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ABSTRACT

Refrigerant 22 flow through short tube restrictors was investigated. The analysis pertained to initially subcooled refrigerant flowing through short tubes with $5 < L/D < 20$. The flow conditions studied were those typically found in heat pumps. Flow dependencies upon upstream subcooling, upstream pressure, downstream pressure, tube length, tube diameter, entrance chamfering and exit chamfering were examined. A correlation and flow charts for mass flow rate prediction were developed from a large experimental data base.

For a given inlet pressure and subcooling, the flow behaved differently depending upon the downstream pressure level. For downstream pressures greater than the approximate liquid saturation pressure of the entering refrigerant, the flow was strongly dependent upon the downstream pressure, as is found for single-phase fluid flowing through a duct. However, for downstream pressures below the saturation pressure, as is typically found during heat pump operation, the flow demonstrated a very weak dependence upon the downstream pressure and could be termed as non-ideal choked flow.

For the case when the downstream pressure was below the saturation pressure, the mass flow rate was directly proportional to upstream subcooling, upstream pressure and cross sectional area, and was inversely proportional to short tube length. The mass flow rate was highly sensitive to inlet chamfering and insensitive to exit chamfering.

Key Words: air conditioner; choked flow; expansion device; heat pump; orifice; plug orifice; restrictor; short tube restrictor

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PREAMBLE

This report is essentially the thesis of David A. Aaron [1] which was submitted to the University of Maryland in partial fulfillment of his Master of Science requirements. The work was performed at the National Institute of Standards and Technology with Piotr A. Domanski directing the project.

TABLE OF CONTENTS

APPENDICES

LIST OF TABLES

LIST OF FIGURES

NOMENCLATURE

A_o	= orifice cross sectional area, (in^2, m^2)
A_s	= short tube cross sectional area, (in^2, m^2)
C	= coefficient of discharge for orifice equation
C_c	= correlation factor for chamfered inlet short tubes
D	= short tube cross sectional diameter, see Figure 5 (in, mm)
DEPTH	= chamfer depth, see Figure 5 (in, mm)
EVAP	= $(P_{sat}-P_{down})/P_{sat}$ (P in absolute pressures psia, kPa) non-dimensional effect of downstream pressure
G	= mass flux
g_{ca}	= dimensional constant, **English units**: **2.8953×10^6 ($lb_m \cdot ft^3/lb_f \cdot in^2 \cdot h^2$)** derived from $32.17 (lb_m \cdot ft/lb_f \cdot s^2) \cdot 1.296 \times 10^7 (s^2/h^2)/144 (in^2/ft^2)$ **SI units**: **1.2960×10^{10} ($s^2 \cdot N/h^2 \cdot kN$)**
H_{fluid}	= enthalpy of the subcooled upstream refrigerant
H_{sat}	= enthalpy of saturated refrigerant at P_1
H_{fg}	= latent enthalpy at P_1
L	= length, see Figure 5 (in, mm)
L/D	= short tube length to diameter ratio
$\dot{m}$	= mass flow rate (lb_m/h, kg/h)
$\dot{m}_a$	= actual mass flow rate (lb_m/h, kg/h)
$\dot{m}_r$	= reference mass flow rate, (lb_m/h, kg/h) read from Figure 29
P_{down}	= downstream (evaporator) pressure, (psia, kPa) see Figure 28
P_{sat}	= upstream refrigerant liquid saturation pressure referenced to the subcooled liquid temperature, (psia, kPa) see Figure 28
P_1	= higher pressure which governs the flow through orifices or short tubes (upstream or condenser pressure), (psia, kPa) Figure 28
P_2	= lower pressure which governs the flow through orifices or short tubes, (psia, kPa)

SUB	= $(T_{sat}-T_{fluid})/T_{sat}$ (T in absolute temperatures °R, K) non-dimensional effect of subcooling
T_A	= temperature at point A in Figure 17
T_{fluid}	= temperature of upstream subcooled fluid, see Figure 28
T_{sat}	= liquid saturation temperature of upstream fluid, see Figure 28
T_X	= temperature at point X in Figure 17
TXV	= thermostatic expansion valve

Greek symbols:

ρ	= upstream liquid density, (lb_m/ft^3, kg/m^3)
β	= ratio of short tube diameter to upstream tube diameter
Φ_1	= correction factor for short tube geometry, Figure 19
Φ_2	= correction factor for subcooling, Figure 20
Φ_3	= correction factor for inlet chamfering, Figure 21
ΔP	= total pressure drop across short tube ($P_1 - P_{down}$)
ΔH	= $H_{sat} - H_{fluid}$

1. INTRODUCTION

A vapor compression heat pump cycle is shown in Figure 1. The task of a heat pump is to remove heat from a lower temperature reservoir and pump it to a higher temperature reservoir [2]. The four basic components are the compressor, condenser, evaporator, and expansion device. This report investigates refrigerant flow through short tube expansion devices (restrictors).

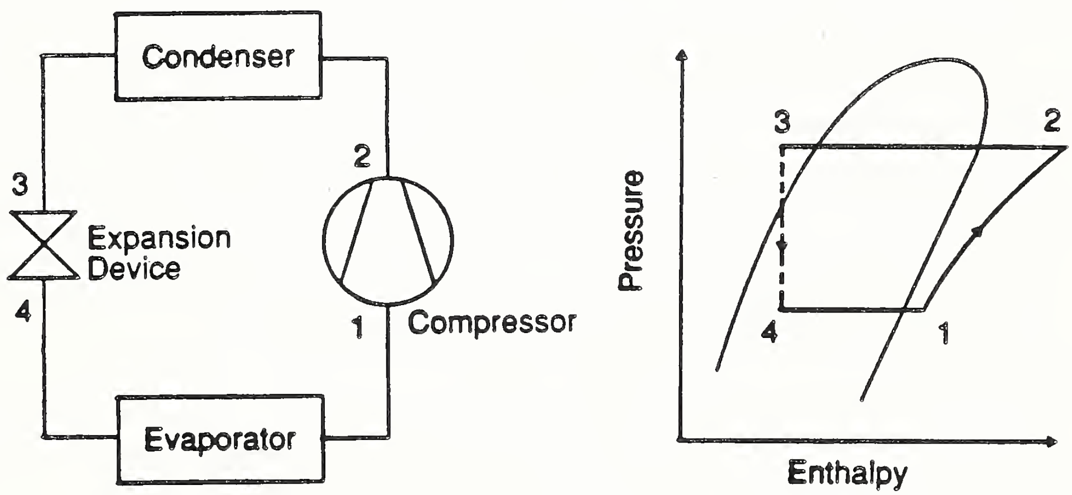

Figure 1. Vapor compression refrigeration cycle.

The purpose of an expansion device is to meter refrigerant from the condenser into the evaporator. The expansion device must balance the flow rate to establish proper pressure and temperature levels in the evaporator and condenser. An ideally sized expansion device will provide optimum system capacity and efficiency while simultaneously insuring that only refrigerant in the vapor phase enters the compressor.

The refrigerant entering an expansion device may either be in a subcooled liquid state or a two-phase state. The refrigerant leaving the expansion device is usually in a two-phase state resulting from the large pressure drop across it. The flashing pressure may be defined as the pressure at which subcooled liquid first begins to bubble or flash. A subcooled liquid will flash as a result of pressure drop and will boil as a result of heat addition. The flashing pressure may be equal to or be below the liquid saturation pressure depending on the presence of metastability. A metastable liquid occurs when the fluid pressure is below the liquid saturation pressure and the flashing process is delayed [3].

There are two basic categories of expansion devices used in residential vapor compression systems. These are variable flow area devices (thermostatic and electric expansion valves) and constant flow area devices (capillary tubes and short tubes). For this discussion, short tubes are defined as having the length to diameter ratio $3 < L/D < 20$. When central air conditioning first became popular in the residential market, the thermostatic expansion valve (TXV) was used extensively as a metering device. Later, the capillary tube began to dominate the market because of its low cost and high reliability with halogenated refrigerants [4].

In recent years, the short tube restrictor has become widely used as an expansion device because, in addition to low cost and high reliability, it offers ease of inspection, ease of replacement, and has been applied in heat pump design such that it allows elimination of additional check valves. For example, heat pumps employing capillary tubes or TXVs require check valves so that refrigerant flow in one direction passes only through the expansion

device while refrigerant flow in the other direction completely bypasses the expansion device. Short tubes possess the unique feature that they can be incorporated in a design where the fluid flow in one direction must pass through a small hole and the flow is restricted or metered (sliding piston). When the fluid direction is reversed, the fluid is allowed to bypass around the short tube, ideally allowing full flow and eliminating the need for an additional check valve.

As a first step in this investigation, previous research on the flow through short tubes was reviewed. Next, an experimental refrigeration loop was constructed and tests were performed. A visual study and pressure profile study were also conducted to learn more about the flow phenomena. A correlation and flow charts for mass flow rate prediction were developed from a large experimental data base. This data may be found in appendices A and B.

2. RESEARCH OBJECTIVES

Because of simplicity of design, reliability, ease of replacement and cost effectiveness, the short tube has recently become one of the more popular metering devices in the residential heat pump market. To date, there is limited theoretical and experimental information on flow through the short tube expansion device.

The mass flow rate prediction models available have either a high degree of empiricism associated with them, are too complex, neglect an important flow parameter(s), apply to different fluids, or apply to a very limited range of operating conditions. Consequently, there is still need for a methodology to predict the mass flow rate through short tubes. The main goals of this study were to derive a simple flow model and to provide flow charts which would allow prediction of mass flow rate through short tubes.

This analysis was limited to the flow of initially subcooled Refrigerant 22 through short tubes having length to diameter ratios between $5 < L/D < 20$. The operating parameters and short tube geometries governing the flow were each individually controlled such that flow dependency to each parameter could be determined. The controlled parameters were upstream subcooling, upstream pressure, downstream pressure, tube length, tube diameter, and inlet and exit chamfering.

3. REVIEW OF PREVIOUS RESEARCH

Fauske [5] and Henry [6] have categorized constant flow area devices by their L/D ratio. A device will have full liquid flow in the form of a free streamline jet if it has $L/D \leq 3$. For devices with $3 \leq L/D \leq 12$, the pressure within the tube remains essentially constant, the liquid jet begins to break up, and the interface mass transfer remains low.

A sharp-edged flat plate orifice, $L/D < 1$, does not choke the flow at normal operating conditions [7] and therefore cannot be employed as an expansion device on a vapor compression system. A constant flow area device which is sensitive to downstream pressure would be detrimental to system performance and reliability. This point is clarified in the "Mass Flow Rate Dependency Upon Downstream Pressure" section.

Single-phase fluids flowing through thin plate orifices have been mathematically described to such a successful degree that orifices are typically employed as flow meters. For assumed incompressible flows, a model has been developed and is referred to as the orifice equation [8]. The theoretical orifice equation is multiplied by a coefficient of discharge which has dependencies upon the ratio of orifice diameter to upstream tube diameter, β, and the Reynolds number, Re. For turbulent flow through orifices, the coefficient of discharge is approximately 0.6. For nozzles, the coefficient of discharge approaches 1.0. For the operating conditions of this investigation, the Reynolds number upstream of the short tube was $Re > 10,000$. Assuming full liquid flow, $Re > 50,000$ for flow inside the short tube. The universally accepted orifice equation is derived from the physical laws governing

single-phase flow and does not involve the complexities of two-phase flows. It has been shown that no critical pressure exists for the thin plate orifice and that flashing does not occur within the orifice [7].

Fluid flowing through a capillary tube behaves quite differently than fluid flowing through an orifice. It has been shown that a choking phenomena exists for capillary tubes, [9-11]. With initially subcooled liquid at the inlet, the flashing process is delayed inside the tube and there is sufficient time for the two-phase fluid to reach near equilibrium at the tube exit. With initially subcooled liquid flowing through capillary tubes, a distinct liquid length and a distinct two-phase length can be calculated [9-13].

Although there has been extensive research on capillary tubes, the two-phase phenomena occurring inside the capillary tube has not yet been understood to the degree necessary for a complete mathematical analysis. Recently, Pate and Tree have demonstrated some success with a critical flow model for a limited range of data [11] and Schulz investigated the non-equilibrium and non-homogeneous effects which occur in capillary tubes [14]. There are empirical charts available which may be successfully used to properly size the capillary tube for a given application [15].

There has been limited research addressing initially subcooled liquid refrigerant flowing through short tubes. Much of the research in the past analyzed flow with saturated or near saturated water at the tube entrance [3,5,16,17]. Bailey [3] investigated the flow of saturated and nearly saturated water through short tubes with $5 < L/D < 20$. Bailey ran experiments using atmospheric upstream pressure with either saturated or slightly

subcooled fluid at the tube inlet. To obtain flow, Bailey varied the vacuum on the downstream side of the short tube and noted three distinct flow regimes as seen in Figure 2.

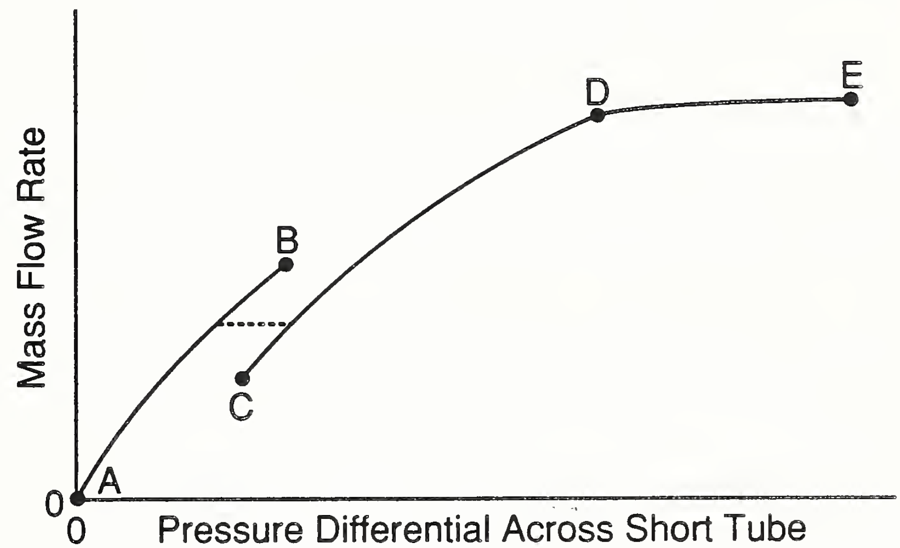

Figure 2. Operating curves for a short tube at constant upstream pressure and temperature.

Curve (AB) represents the conventional single-phase $G \alpha \Delta P$ relationship where the fluid is subcooled at all points in the tube. Near point B, the pressure near the vena contracta (the smallest flow area caused by sudden contraction) was at a value close to the liquid saturation pressure, P_{sat}, corresponding to the upstream liquid temperature. As the downstream pressure was varied near points B and C, Bailey noted an instability in the flow; the operating points shifted back and forth from curve (AB) to curve (CD). Upon further reduction of the downstream pressure, the flow reestablished the $G \alpha \Delta P$ relationship until point D was reached where the flow became essentially choked. For region (DE), Bailey formed a critical flow model based on the rate of evaporation from a metastable liquid core into a surrounding ring of vapor.

Zaloudek [16] investigated water flowing through short tubes with L/D < 6. Zaloudek found the same operating curves as Bailey, Figure 2. However, he found stable operating points between curves (AB) and (CD) which is represented by the dotted line. Zaloudek observed no difference in the mass flow rate from the transition between curves (AB) and (CD) and hence termed the phenomena first-step critical flow or first stage choking. The region Bailey termed as critical, from points D to E, Zaloudek termed as second-step critical or second stage choking. Our investigation covers region (CDE) and therefore cannot confirm the observations of Bailey and Zaloudek in region (ABC).

Zaloudek noted that his experimental data approximated both the surface tension model proposed by Burnell [17], and by Kinderman and Wales [18], and the surface evaporation model proposed by Bailey [3]. This may indicate the high degree of empiricism associated with the models because they describe the flow from two different viewpoints. Zaloudek determined that the pressure near the vena contracta closely approximated P_{sat}. Zaloudek's data (for L/D < 6) suggested a slight mass flow dependency upon tube length, however, he could make no correlation due to experimental data scatter.

Pasqua [19] investigated the flow of R-12 through glass short tubes. With initially subcooled fluid entering the short tube, Pasqua's photographs showed that the fluid flashed inside the short tube when the downstream pressure was near or below the liquid saturation pressure. The fluid inside the short tube was described as a metastable inner core of liquid with a surrounding two-phase annular ring. Other researchers have confirmed the existence of metastable flow in the short tube [3,5,6,16]. The vena contracta, which is typically present just beyond the tube entrance for full liquid

flow, cannot be defined in the same manner for two-phase flow. From Pasqua's photographs, one can observe the metastable liquid core decrease in diameter as the fluid proceeds to the tube exit. This suggests that evaporation (flashing) continues along the short tube. Pasqua derived a flow model for short tubes with saturated R-12 at the inlet.

Henry developed a non-equilibrium model to predict the critical flow rate through short tubes with L/D > 12 and extended the analysis to L/D < 12 [6]. The extended model assumed a homogeneous two-phase flow with negligible friction and further assumed a smooth inlet geometry where the coefficient of discharge approached 1.0. Henry also discussed whether the L/D ratio is a correct means of comparing experimental data. He concluded that the data he compared with the same L/D ratios but with different lengths and diameters were in good agreement with his model. He added that this analysis did not definitely prove that the L/D ratio is a valid scaling factor.

Collins analyzed use of the isentropic homogeneous equilibrium model for the choked expansion of subcooled water [20]. He found that the model over-predicted the mass flow rate and concluded that the choking phenomena does occur in short tubes. He indicated that choking may be controlled by the strong discontinuity of the acoustic speed in spite of the highly metastable character of the fluid.

Mei investigated the flow of initially subcooled R-22 through short tubes with 7 < L/D < 12 [21]. Mei stated that what Zaloudek termed first stage choking has occurred when the inlet subcooling was larger than 40°F (22.2°C). For the normal heat pump operating range (subcooling < 40°F),

Mei reported no evidence of choking. Accordingly, Mei proposed a choked flow model for R-22 flow with subcooling above 40°F and a non-choked model for subcooling less than 40°F. Mei later added a correlation relating exit quality and the L/D ratio [22].

Krakow and Lin investigated the flow of R-12 through capillary tubes, orifices, and short tubes [23]. They observed that flow through short tubes with $2 < L/D < 7$ was primarily dependent upon the upstream refrigerant conditions and not on the downstream pressure, thus a choking phenomena was indicated for short tube flow. They presented two methods for predicting mass flow rate. Their final correlation was based on the amount of upstream subcooling.

If indeed the fluid is choked for flow through short tubes, then one could obtain the critical mass flow rate of the fluid. To do this, one must be able to successfully calculate the sonic velocity of the fluid at critical conditions. Given that the flow inside the short tube is heterogeneous, use of the homogeneous sonic velocity is fundamentally incorrect. However, the homogeneous sonic velocity must be understood in order to begin comprehension of sonic velocity in heterogeneous fluids.

A review on sonic velocity in two-phase homogeneous fluids is presented by Gouse and Brown [24]. There is a sharp discontinuity in sonic velocity at the liquid saturation line. Sonic velocity is found to be a minimum at the liquid saturation line, two orders of magnitude less than for subcooled liquid, and gradually increase as the quality increases. Homogeneous two-phase sonic velocity has been shown to be mostly a function of the quality and temperature of the fluid. Analytical results indicate that once

flashing occurs in a subcooled liquid, effects of compressibility can no longer be neglected. Derivation of the sonic velocity for homogeneous two-phase fluids includes the following assumptions:

the mixture is homogeneous in phase composition,

the process is isentropic,

the two-phase mixture is always in thermodynamic and mechanical equilibrium; no temperature or pressure gradients exist in the axial direction in the mixture,

equilibrium of the mixture is not disturbed by the passage of infinitesimal pressure waves passing through it.

The fact remains that sonic velocity in assumed homogeneous or heterogeneous two-phase fluids is not yet fully understood. Wallis and also Hsu and Graham have discussed in detail the various models available for two-phase critical flows [25,26]. Wallis has stated that "those readers associated with the difficulties of making any two-phase gas-liquid flow situation 'well defined' will appreciate that we should perhaps not expect to be able to be too precise in our description of these phenomena." Hsu and Graham stated that one mistake made by investigators is to analyze a two-phase flow from a single-phase flow viewpoint.

Models assuming equilibrium flow include the homogeneous equilibrium model, frozen flow model, slip flow model, and isentropic stream-tube models. The non-equilibrium models include analysis of vapor bubble generation, interphase heat, mass and momentum transfer, multidimensional effects and developing two-phase patterns. A detailed review of these models is beyond the scope of this investigation but can be found in [25,26].

Wallis appropriately concluded that "there are so many uncertainties about the physics (in two-phase critical flows) that one merely ends up trying to fit the critical data by varying adjustable coefficients that are made respectable by being given names implying that they describe physical phenomena."

In summary of the literature review, an acceptable flow model which could predict the mass flow rate through short tubes could not be found. The models available have either a high degree of empiricism associated with them, are too complex, neglect an important parameter(s), apply to different fluids, or apply to only a limited range of operating parameters. In addition, empirical charts such as those used to size capillary tubes could not be found. Further, it is still unclear whether or not the fluid is choked within the normal operating pressures and temperatures of heat pumps.

4. EXPERIMENTAL TEST LOOP

A schematic diagram and photograph of the experimental refrigeration loop are shown in Figures 3 and 4. The loop was specifically designed such that each influential operating flow parameter could be individually controlled while keeping the other parameters constant. The operating parameters were upstream subcooling, upstream pressure, and downstream pressure. The loop was also designed to allow easy installation and removal of the various short tubes tested.

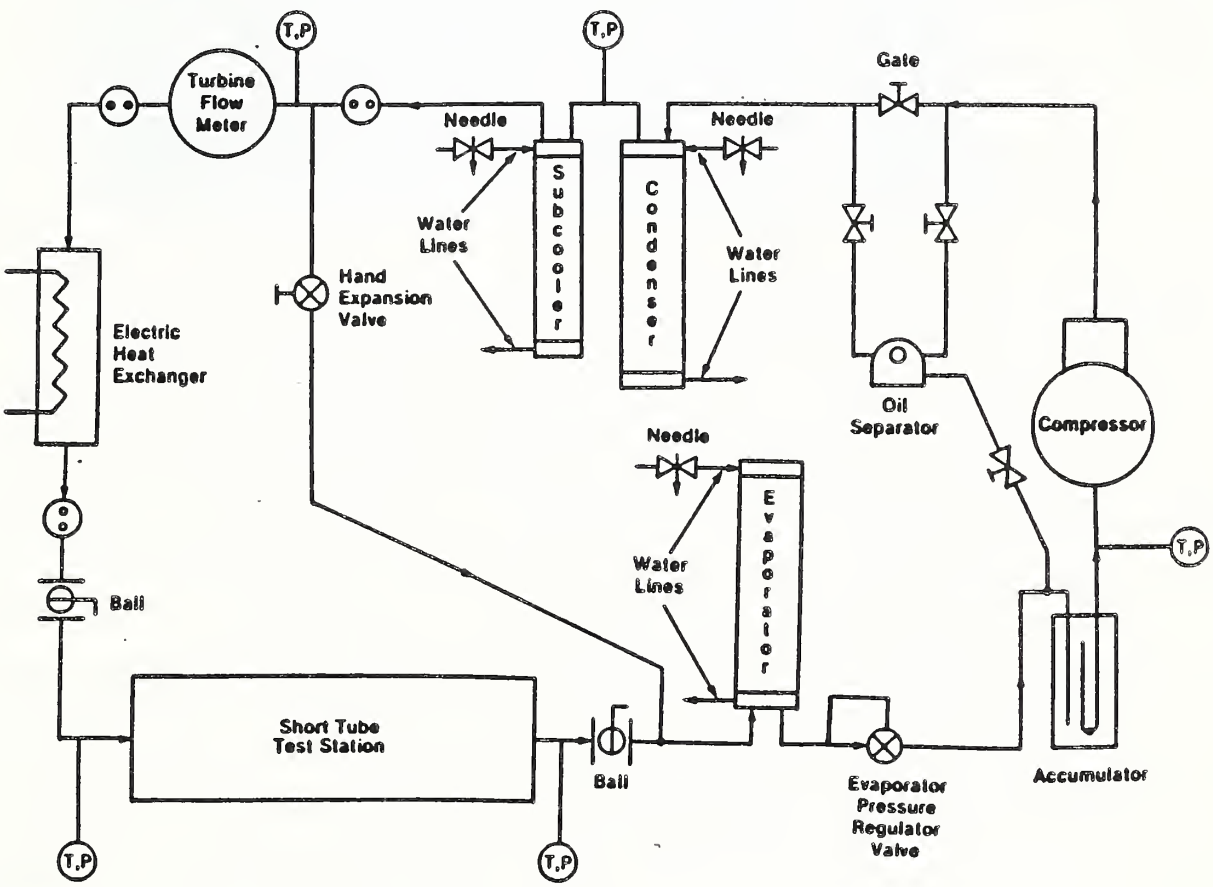

Figure 3. Schematic of the short tube test loop.

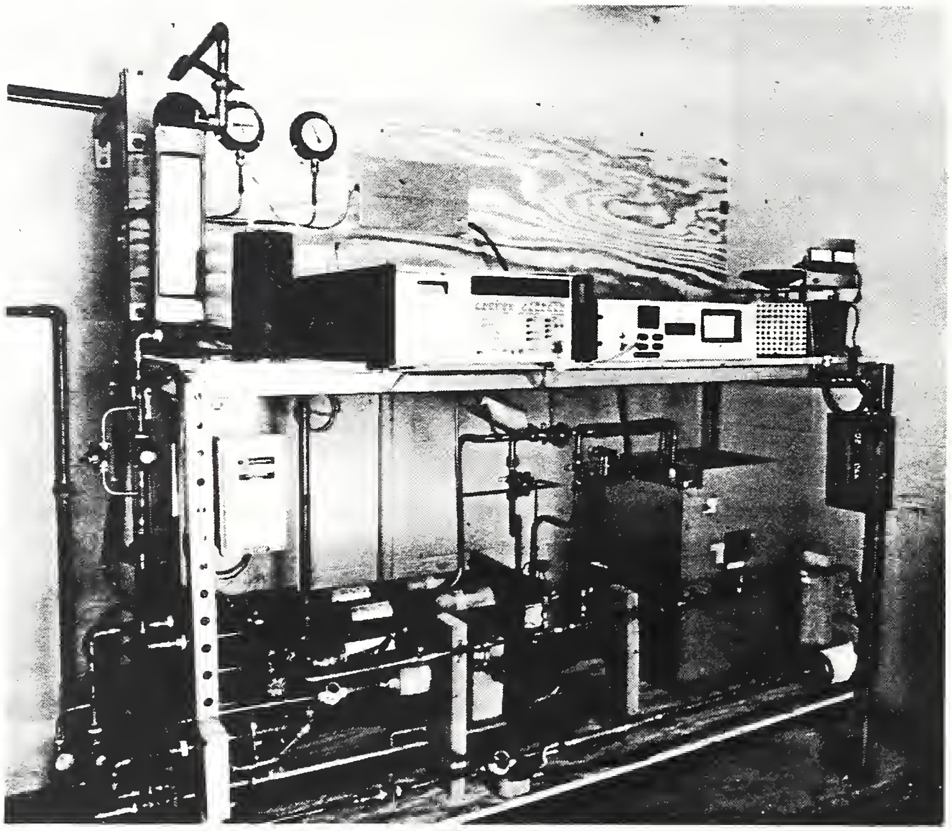

Figure 4. Photograph of the short tube test loop.

A two-speed compressor equipped with a suction line accumulator was utilized to provide a large range of mass flow rates. Mass flow rates during tests ranged approximately from 100-700 lb_m/h (45-318 kg/h). An oil separator was used to insure low oil contamination in the circulating refrigerant, although the oil content was not measured. Water cooled/heated heat exchangers were used for the condenser and evaporator. The water flow rate in the condenser was controlled by a head pressure activated flow valve. At times when the flow became unstable, typically at lower subcooling levels, a manually operated needle valve was used to control the flow. The water fed to the condenser was chilled water at 42°F (6°C). Mixed hot and cold water was

metered by a needle valve into the evaporator to supply the load and control the refrigerant superheat. A separate liquid subcooler was located before the turbine meter to insure that subcooled liquid was present at the turbine meter inlet. The water feeding the subcooler was at 42°F (6°C).

An electric heater with adjustable capacity from 0-11,260 Btu/h (0-3.3 kW) was used to reheat the liquid refrigerant to the desired level of subcooling. Three 3,754 Btu/h (1.1 kW) strip heaters were mounted horizontally along a three foot (one m) section of the liquid line. Insulation, equipped with two ten junction thermocouples, was installed over the electric heater. The power input to the electric heater, the inside and outside temperature of the heater insulation, and the temperature change of the refrigerant across the heater were measured. The energy balance provided a secondary measurement of the flow rate.

To control the downstream (evaporator) pressure, a hand operated expansion valve was utilized to bypass liquid refrigerant from the liquid line directly to the evaporator inlet. The evaporator load was adjusted to maintain a 10-30°F (5-15°C) superheat to prevent liquid droplets from entering the compressor.

Ten pressure transducers were calibrated with a standard dead weight tester. All calibration data can be found in [1]. The estimated accuracy of pressure measurement was $\pm$ 0.15% of full scale reading. The calibration of each pressure transducer was checked after four months of operation to insure correct measurement. The new values were found to be within $\pm$ 0.05 % of the original calibration.

Copper-constantan thermocouples were used to measure temperatures. Calibration was performed by adjusting a potentiometer located on each isothermal block in the data acquisition system. The accuracy of the temperature measurement was estimated at $\pm$0.25°F ($\pm$ 0.15°C). Three individual thermocouples were used to measure the temperature at each location. The temperature inside and outside the electric heater insulation was measured using two ten junction thermocouples. Calibration of the heat lost through the heater insulation included determination of the conductance of the insulation as a function of the integrated mean operating temperature [27]. The experimental conductance data were within 10% from the results found in the literature for a similar insulation [28].

The temperature of the liquid refrigerant at the inlet and outlet of the electric heater was measured in order to calculate the change in enthalpy across the heater to use in the secondary mass flow rate measurement. At first, it was observed that the refrigerant temperature at the heater outlet was not uniform resulting in considerable temperature measurement errors. The nonuniform temperature was attributed to the large amount of heat transfer occurring in the small area provided. Local fluid boiling was occurring on the tube walls.

To resolve the measurement difficulty, the temperature of the refrigerant was measured approximately 10 feet (3 m) downstream from the heater outlet where the refrigerant reached equilibrium. The heat loss from between this temperature measurement and the heater outlet was calculated such that the heater outlet temperature could be predicted.

A digital-analogue watt-hour meter was used to measure the power input to the heater. A standard watt-hour meter was used for calibration. It was estimated that the measurement of power was within $\pm$ 0.5% of the full scale reading.

The turbine meter was calibrated and found to be within 0.2% of the ten point factory calibration. Calibration was performed by measuring the volume of water which flowed into a measuring tank per unit time. The volume of the water and the time intervals were made large enough such that measurement errors became negligible. The error in mass flow measurement produced by the viscosity difference between R-22 and the calibration fluid, water, was taken as negligible. This was supported by literature provided by the manufacturer [29] and by comparing the mass flow rates between the electric heater and turbine meter methods.

It was estimated that an accuracy $\pm$ 0.5% for the turbine meter and $\pm$ 4% for the electric heater method could be realized. The electric heater method was less accurate because of the number of inputs necessary for use in the energy balance. Agreement of the two different flow measurements was used as a stability check before any data was acquired. All calibration data may be found in [1].

5. EXPERIMENTAL SHORT TUBES

The length, diameter, chamfer depth, and material of the short tubes tested were based on commercially available short tubes used in residential heat pumps. Short tubes were made for the study in order to eliminate the possibility of bypass leakage associated with the piston short tube design or material imperfections. Diameters were bored and then reamed for a smooth, burr free, interior finish. The brass short tubes were installed into the test loop by soft soldering them between two 3/8 in (9.525 mm) O.D. copper tubes. A schematic describing the length, diameter, and chamfer depth of the short tubes is presented in Figure 5.

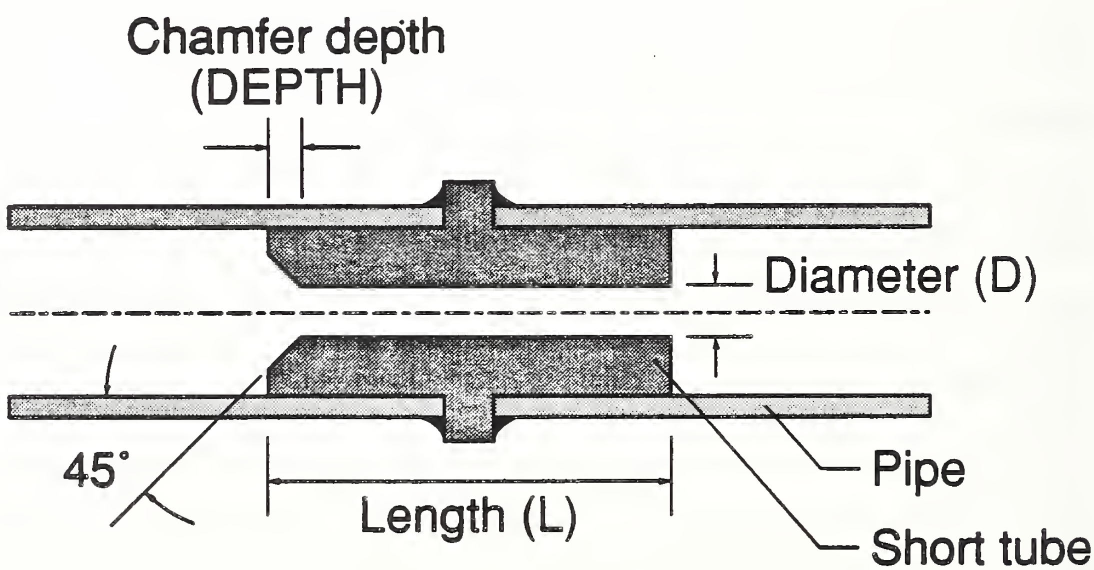

Figure 5. Schematic of a short tube soldered between copper pipes.

Some of the test short tubes were chamfered. Chamfer depths were chosen to cover the depth range found in commercially available short tubes. The chamfers were cut at 45°. The short tubes were chamfered on only one side and were tested with flow through each direction. This allowed the effect of inlet and exit chamfering to be studied separately.

Table 1 lists the short tubes that were tested in this investigation.

Table 1. Dimensions of the tested short tubes.

Short tube	Diameter		Length		Chamfer Depth (@45°)	
	(in)	(mm)	(in)	(mm)	(in)	(mm)
1	0.0438	1.11	0.3750	9.53	sharp-edged	
2	0.0440	1.12	0.5005	12.71	sharp-edged	
3	0.0438	1.11	0.5000	12.70	0.0103	0.26
4	0.0532	1.35	0.3755	9.54	sharp-edged	
5	0.0522	1.33	0.3750	9.53	0.0091	0.23
6	0.0526	1.34	0.3775	9.54	0.0148	0.38
7	0.0530	1.34	0.5005	12.71	sharp-edged	
8	0.0527	1.34	0.5000	12.70	0.0084	0.21
9	0.0533	1.35	0.5010	12.73	0.0138	0.35
10	0.0529	1.34	0.5000	12.70	0.0197	0.50
11	0.0533	1.35	1.0000	25.40	sharp-edged	
12	0.0531	1.35	1.0000	25.40	0.0039	0.10
13	0.0534	1.36	1.0000	25.40	0.0070	0.18
14	0.0534	1.36	1.0000	25.40	0.0182	0.46
15	0.0680	1.73	0.3760	9.55	sharp-edged	
16	0.0678	1.72	0.3770	9.58	0.0112	0.28
17	0.0679	1.72	0.3750	9.53	0.0134	0.34
18	0.0678	1.72	0.4995	12.69	sharp-edged	
19	0.0680	1.72	0.5000	12.70	sharp-edged	
20	0.0677	1.72	0.5005	12.71	0.0081	0.21

Diameters and chamfer depths were measured using a shadowgraph with 100 times magnification. Lengths were measured with electronic calipers. The accuracy of both measurements was estimated at ± 0.0005 in (± 0.01 mm).

The pressure profile was studied using a short tube equipped to measure the upstream, inside, and downstream pressure. A schematic of this short tube is shown in Figure 6.

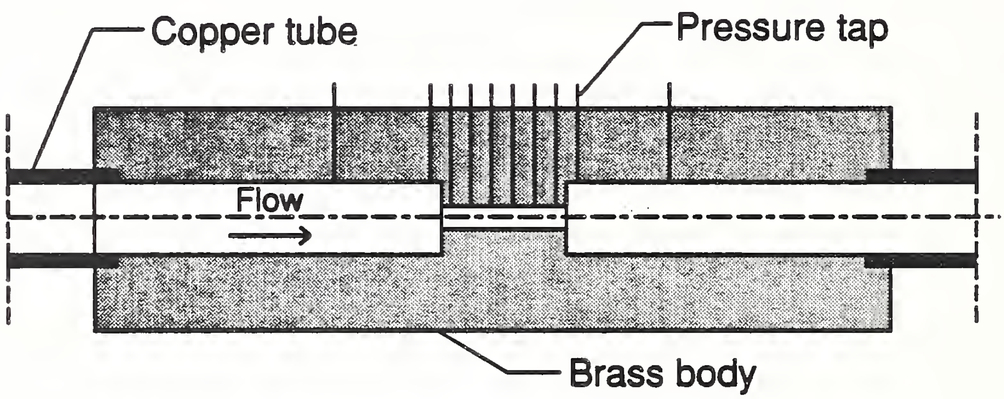

Figure 6. Schematic of the short tube equipped to measure pressure.

There were six pressure taps located within the short tube length such that the pressure along the length of the short tube could be measured. These pressure taps were bored to 0.003 in (0.076 mm) in diameter using electronic discharge machining, EDM. Pressure taps located before and after the short tube were bored to 0.02 in (0.508 mm) such that upstream and downstream pressure could be measured. The pressure taps were staggered such that the wake produced from each tap had no effect on taps further downstream. A complete set of drawings and specifications may be found in [1].

Both before and after the EDM process, the mass flow rates at various upstream and downstream conditions were measured and were found to be within ± 0.5% of each other. Therefore, the pressure taps were assumed to have no appreciable effect on the mass flow rate. A photograph of the short tube used to measure the pressure profile is shown in Figure 7. Ten pressure transducers were connected to the pressure taps.

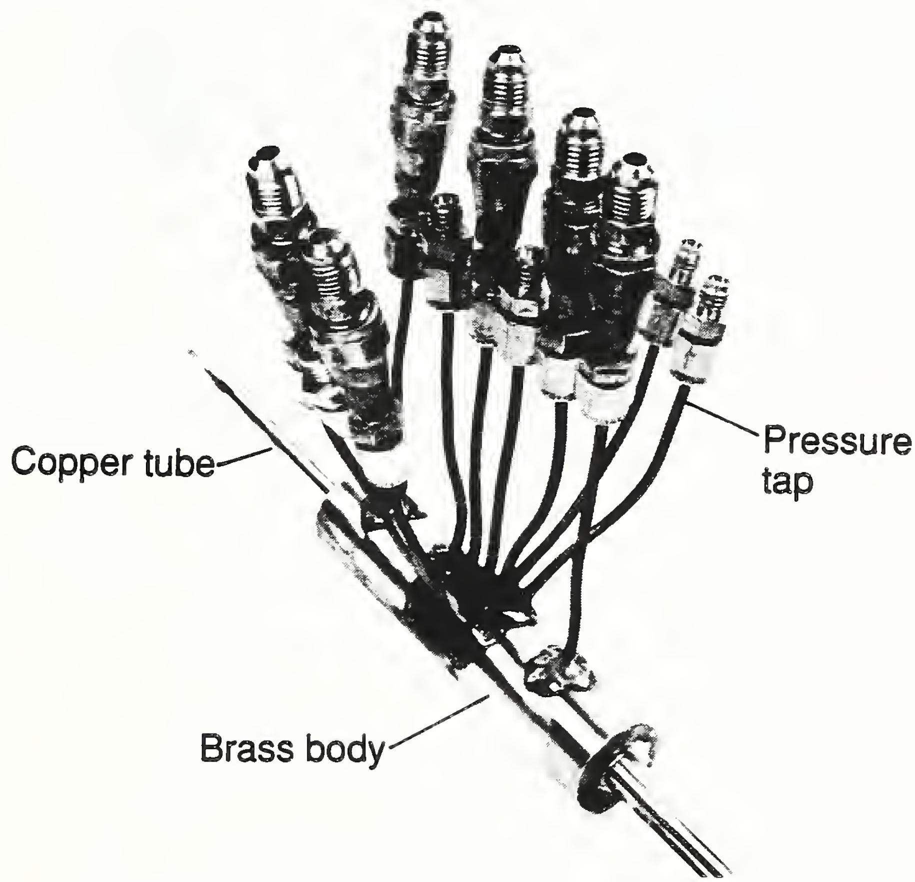

Figure 7. Photograph of the short tube equipped to measure pressure.

A short tube was installed inside a glass tube such that a visual observation of the upstream and downstream flow conditions could be performed. The perimeter of a brass short tube was lathed such that an o-ring fit snugly around it. This o-ring provided a tight seal between the outside of the

short tube and the inside of the glass tube. The short tube was maintained in place by a copper support wire which was soldered to the edge of the short tube and to the inside of the upstream copper pipe. The support wire prevented the short tube from traversing down the glass tube during operation, see Figure 8.

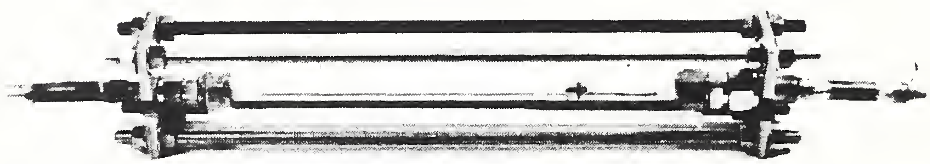

Figure 8. Photograph of a short tube mounted inside a glass tube. Dimensions: L=0.375 in (9.5 mm), D=0.068 in (1.73 mm)

6. TESTING CONDITIONS

Three types of experiments were conducted:

a) performance tests to generate a broad mass flow rate data base

b) pressure profile observation tests

c) flow visualization tests

Testing conditions were selected to cover the operating range for a short tube restrictor found in a typical residential heat pump. Upstream (condenser) pressure at 250 psia (1724 kPa), downstream (evaporator) pressure at 91 psia (627 kPa), and subcooling at 17.5°F (10°C) were chosen as base operating conditions. To capture nonlinear trends and to extend the analysis, conditions above and below the base point were selected.

The 27 different performance tests conducted on each short tube are listed in Table 2. Data were taken once steady state conditions were obtained in the loop. Tests at each specified operating condition were repeated three times to assure repeatability. For each test, the following variation limits were placed on the parameters before data were accepted: upstream pressure ±2 psia (±13.8 kPa); subcooling ±0.2°F (±0.1°C); downstream pressure ±1 psia (±6.9 kPa). Once the flow was found to be fairly insensitive to downstream pressure, the downstream pressures above and below 91 psia (represented by 50 and 120 psia in Table 1) were allowed to be set ±20 psia from the specified values. This allowed faster stabilization of the loop at the required inlet pressure and subcooling (true downstream pressures were used in the correlation process).

Pressure and temperature gradients were kept to within the limits listed above. Experience with the loop showed that the turbine meter flow measurement and the secondary electric heater flow measurement had to agree within ± 3% before the flow could be considered steady.

TABLE 2. Short tube test conditions.

Test #	Upstream Pressure (psia)	Upstream Pressure (kPa)	Downstream Pressure (psia)	Downstream Pressure (kPa)	Subcooling (°F)	Subcooling (°C)
Test1	210	1448	120	827	10	5.6
Test2	210	1448	91	627	10	5.6
Test3	210	1448	50	345	10	5.6
Test4	210	1448	120	827	17.5	9.7
Test5	210	1448	91	627	17.5	9.7
Test6	210	1448	50	345	17.5	9.7
Test7	210	1448	120	827	25	13.9
Test8	210	1448	91	627	25	13.9
Test9	210	1448	50	345	25	13.9
Test10	250	1723	120	827	10	5.6
Test11	250	1723	91	627	10	5.6
Test12	250	1723	50	345	10	5.6
Test13	250	1723	120	827	17.5	9.7
Test14	250	1723	91	627	17.5	9.7
Test15	250	1723	50	345	17.5	9.7
Test16	250	1723	120	827	25	13.9
Test17	250	1723	91	627	25	13.9
Test18	250	1723	50	345	25	13.9
Test19	291	2006	120	827	10	5.6
Test20	291	2006	91	627	10	5.6
Test21	291	2006	50	345	10	5.6
Test22	291	2006	120	827	17.5	9.7
Test23	291	2006	91	627	17.5	9.7
Test24	291	2006	50	345	17.5	9.7
Test25	291	2006	120	827	25	13.9
Test26	291	2006	91	627	25	13.9
Test27	291	2006	50	345	25	13.9

For the short tube equipped with pressure taps, additional data were collected from that listed in Table 2. The downstream pressure was varied such that observation of the pressure profile at, well above, and well below the liquid saturation pressure, P_{sat}, referenced to the upstream subcooled liquid temperature could be studied.

For the short tube visual study, photographs were taken at various flow conditions. The downstream pressure was varied above and below P_{sat}. In addition, the downstream pressure was measured just at the onset of flashing in order to observe the relationship, if any, between the flashing pressure and P_{sat}.

7. MASS FLOW RATE DEPENDENCY UPON DOWNSTREAM PRESSURE

Figure 9 shows the mass flow rate as a function of downstream pressure at three different upstream pressures. All of the experimental data may be found in appendices A and B. There exists a discontinuity in the flow phenomena when the downstream pressure approaches the liquid saturation pressure, P_{sat}, referenced to the upstream subcooled liquid temperature.

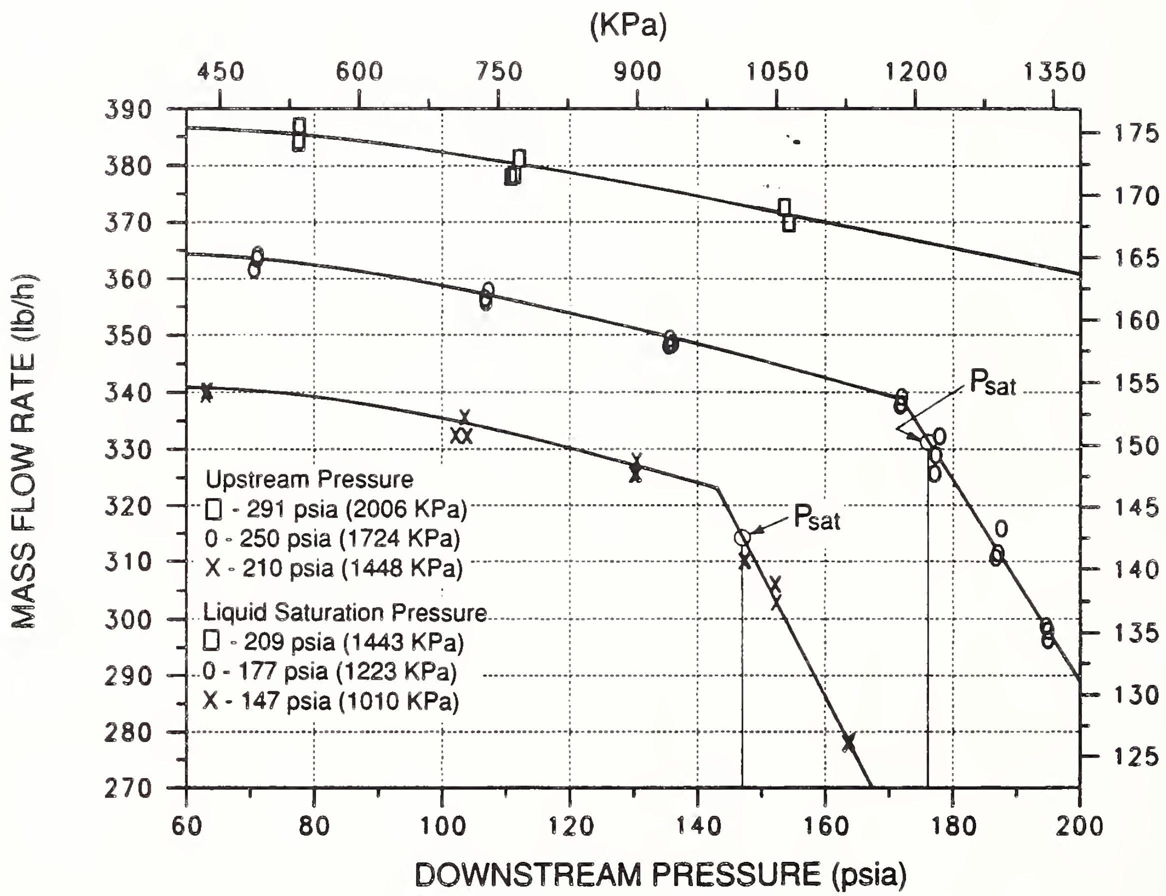

Figure 9. Mass flow dependency upon downstream pressure for a typical short tube. Conditions: L=0.5 in (12.7 mm), D=0.053 in (1.35 mm), subcooling 25°F (13.9°C)

When the downstream pressure was above P_{sat} (subcooled liquid throughout), the mass flow rate was very dependent upon the downstream pressure. For flows with subcooled liquid on both sides of the short tube, flow models using expansion and contraction coefficients have been developed [30].

When the downstream pressure was below P_{sat} (liquid flashing inside the short tube), the flow rate became fairly insensitive to the downstream pressure. This investigation mainly concentrates on this flow situation, when $P_{down} < P_{sat}$. The mass flow rate increased typically 3 to 8% from the time when the downstream pressure was near P_{sat} to the time when the downstream pressure was at a minimum value. The lowest obtainable operating downstream pressure in the loop was approximately 30 psia (208 kPa). All the short tubes tested displayed a slight sensitivity to downstream pressure regardless of any other parameter. Since the evaporator pressure for typical heat pump operation is considerably lower than P_{sat}, one can conclude that the choked flow phenomena occurs for heat pumps employing short tubes. A critical downstream pressure, below which the mass flow rate has no dependency upon the downstream pressure, was never obtained within the minimum operating downstream pressure of the loop.

Because the mass flow rate has a small dependency upon downstream pressure, it is technically incorrect to term the flow "choked". Choked flow has been defined as the phenomenon which occurs when the mass flow rate remains constant with further reduction in downstream pressure [31]. Choking occurs when the fluid reaches the velocity of the downstream pressure waves so downstream state information cannot propagate upstream.

A complication of this matter comes from the fact that choking is typically defined for a single-phase fluid, usually a gas. The fluid flowing through the short tube, however, has been observed to be in a separated two-phase state [3,5,6,16,19]. When choking occurs in a single-phase flow, the sonic velocity, pressure wave velocity, and fluid velocity are all identical. With two-phase flow, this may or may not be true. It may be possible that choking occurs in the vapor phase and not in the liquid phase with substantial slip between the two phases.

The 3 to 8% change in mass flow rate was observed for a considerably larger change in the downstream pressure than for those typically occurring in heat pumps. For downstream pressure changes typical for heat pumps, the change in mass flow rate would be smaller, not exceeding 3%. For this reason, flow dependency upon downstream pressure has typically been assumed negligible in the past. Review of the literature on flow through short tubes and capillary tubes showed that the flow has customarily been termed "choked". Therefore, to keep with the same terminology, the term "choked", although meaning approximately choked, will be used from this point on to describe the flow phenomena.

For proper system operation and reliability, a constant flow area expansion device should choke the flow of refrigerant. Consider that when the load to an evaporator increases, the evaporator pressure and demand for more refrigerant flow to the evaporator both increase. A constant flow area device which is sensitive to an increase in evaporator pressure, however, would be forced to feed less refrigerant. Conversely, when evaporator pressure drops due to a decrease in load and less refrigerant flow is

required, the flow device which is sensitive to downstream pressure would be forced to feed more refrigerant. Thus, if a constant flow area expansion device does not choke the flow, either a completely flooded evaporator or a high superheat condition would result depending on the downstream pressure. This in turn would cause poor system performance and effect reliability.

Comparison of short tube flow to the capillary tube flow reveals that both constant flow area expansion devices are identical from a macroscopic operational view point. Both devices tend to choke the flow, a must for heat pump applications. In a recent study of the choked flow through capillary tubes, Pate and Tree [11] present experimental results, shown in Figure 10, which look very similar to Figure 9 from this study.

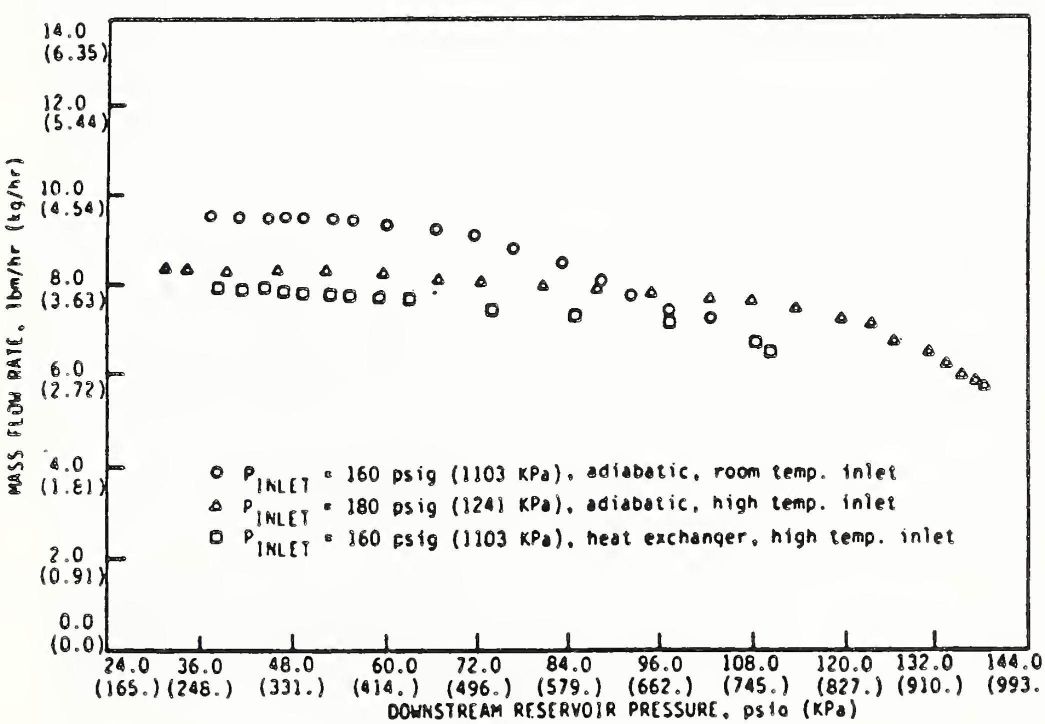

Figure 10. Results from the Pate and Tree study on the choked flow through capillary tubes [11].

Figure 10 shows that the flow rate through a capillary tube is slightly dependent on the downstream pressure for quite a large range of evaporator pressures. Bolstad and Jordan [9] displayed a similar graph for flow through a capillary tube, given here as Figure 11. They explained that for most of their tests, the evaporator pressure could be neglected but specifically used this figure to illustrate that the evaporator pressure does have a slight effect on the flow rate through capillary tubes. Figures 10 and 11 suggest that it is difficult to conclude that flow through a capillary tube is ideally choked.

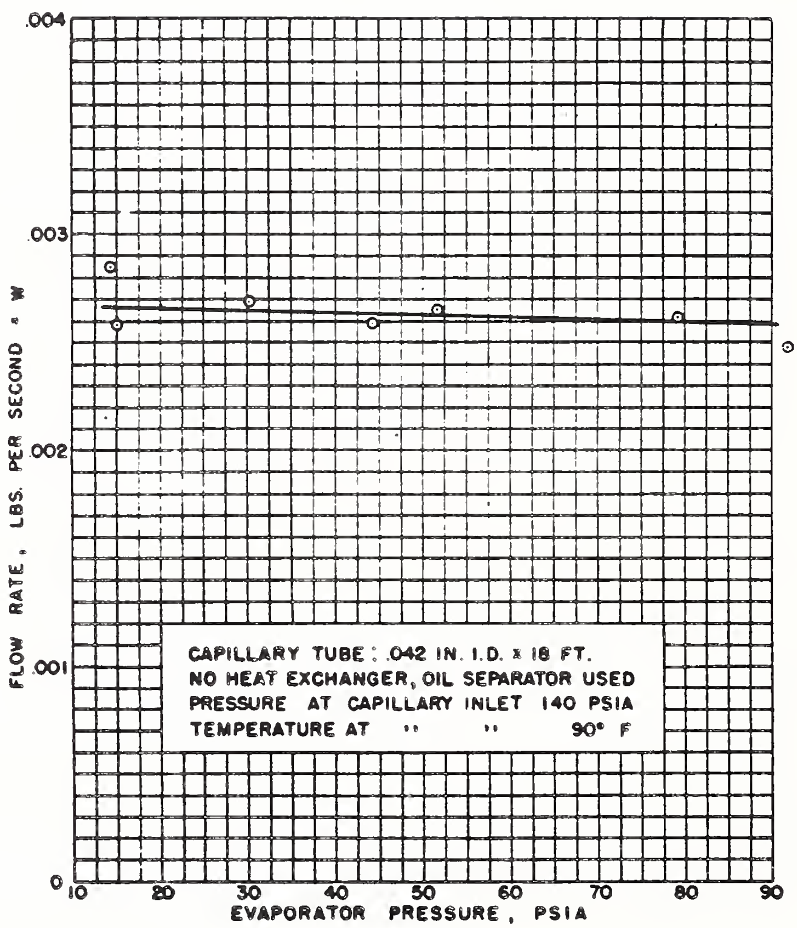

Figure 11. Results from the Bolstad and Jordan study, "The effect of evaporator pressure on flow rate for a typical capillary tube" [9].

The pressures measured upstream, downstream, and inside a short tube are shown below in Figure 12. The upstream and downstream pressure levels in the figure are representative of typical heat pump operating conditions.

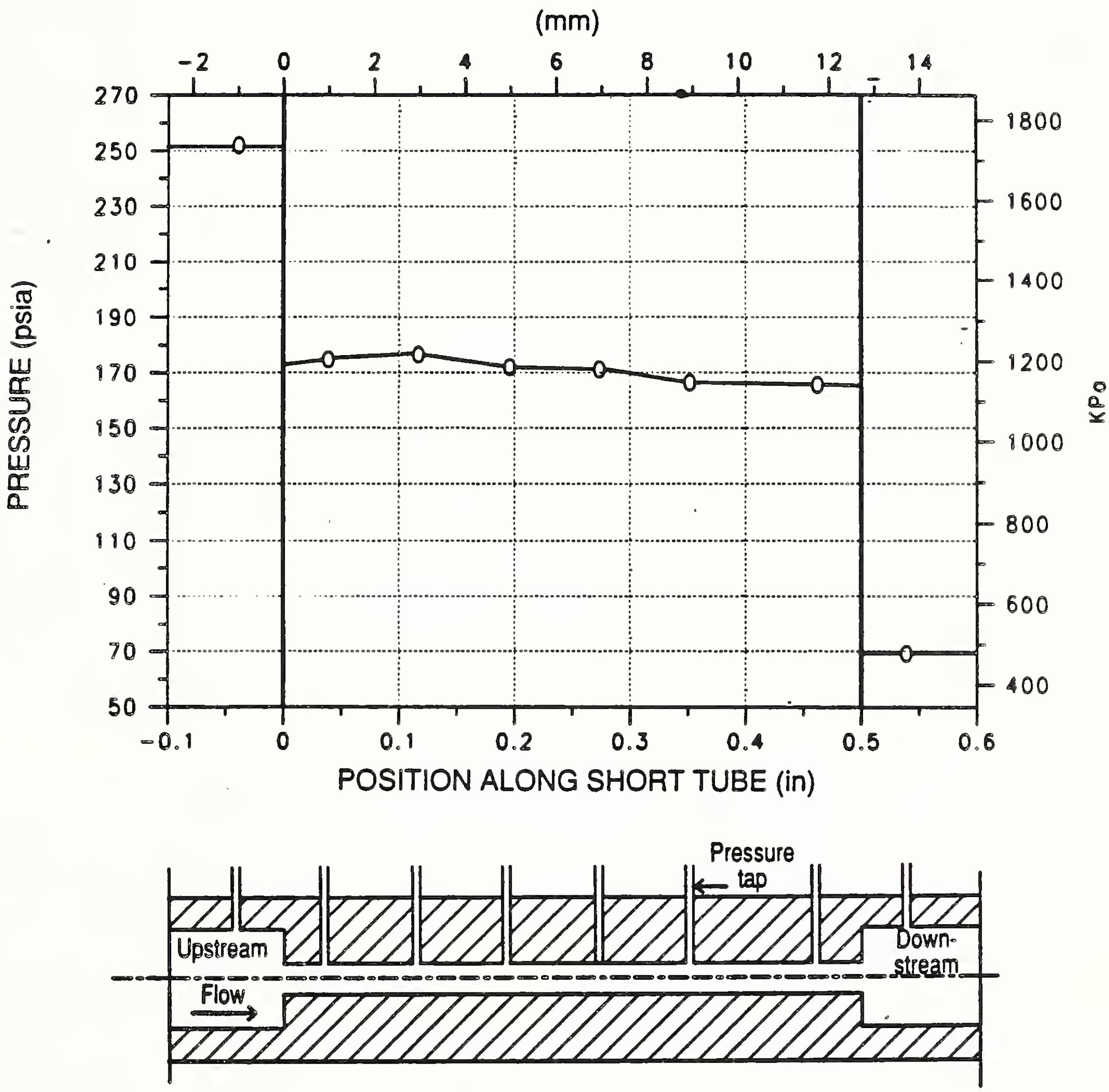

Figure 12. Pressure profile through the short tube for typical heat pump operating conditions. Conditions: L=0.5 in (12.7 mm), D=0.053 in (1.35 mm), subcooling 25°F (13.9°C)

There is a slight pressure drop inside the short tube. A small dip in pressure at the first pressure tap inside the short tube and then the pressure recovery at the second pressure tap indicate rapid fluid acceleration

near the vena contracta. It is difficult, however, to describe a vena contracta in a two-phase flow in the same manner as with a single-phase flow. For example, the liquid does not diverge back to the wall as it does with full liquid flow, rather the liquid remains in a core separated from the tube wall which decreases its diameter along the flow length [19]. To investigate the pressure recovery at the second pressure tap the fluid flow direction was reversed. In both flow directions, the short tube displayed the same pressure profile.

Figure 12 shows that a large change in pressure exists at both the inlet and exit of the tube. The large pressure drop at the entrance is due to the rapid contraction in the flow area and is consistent with sudden flow acceleration. The large pressure drop in the exit plane would indicate a choked condition for single-phase flows. For the two-phase flow in the short tube, one may conclude that the large pressure drop in the exit plane indicates that the flow is at least approximately choked.

The pressure profile at various downstream pressures, keeping upstream pressure and subcooling constant, is shown in Figure 13. The most significant finding from the figure is that reduction of downstream pressure causes a drop in pressure throughout the entire short tube, thus the choking cannot be ideal. One may conclude that the downstream pressure waves are at a higher velocity than the refrigerant and accordingly can communicate information upstream.

The sonic velocity in a two-phase homogeneous fluid has been analytically shown to be mostly a function of quality and temperature [24]. There is not

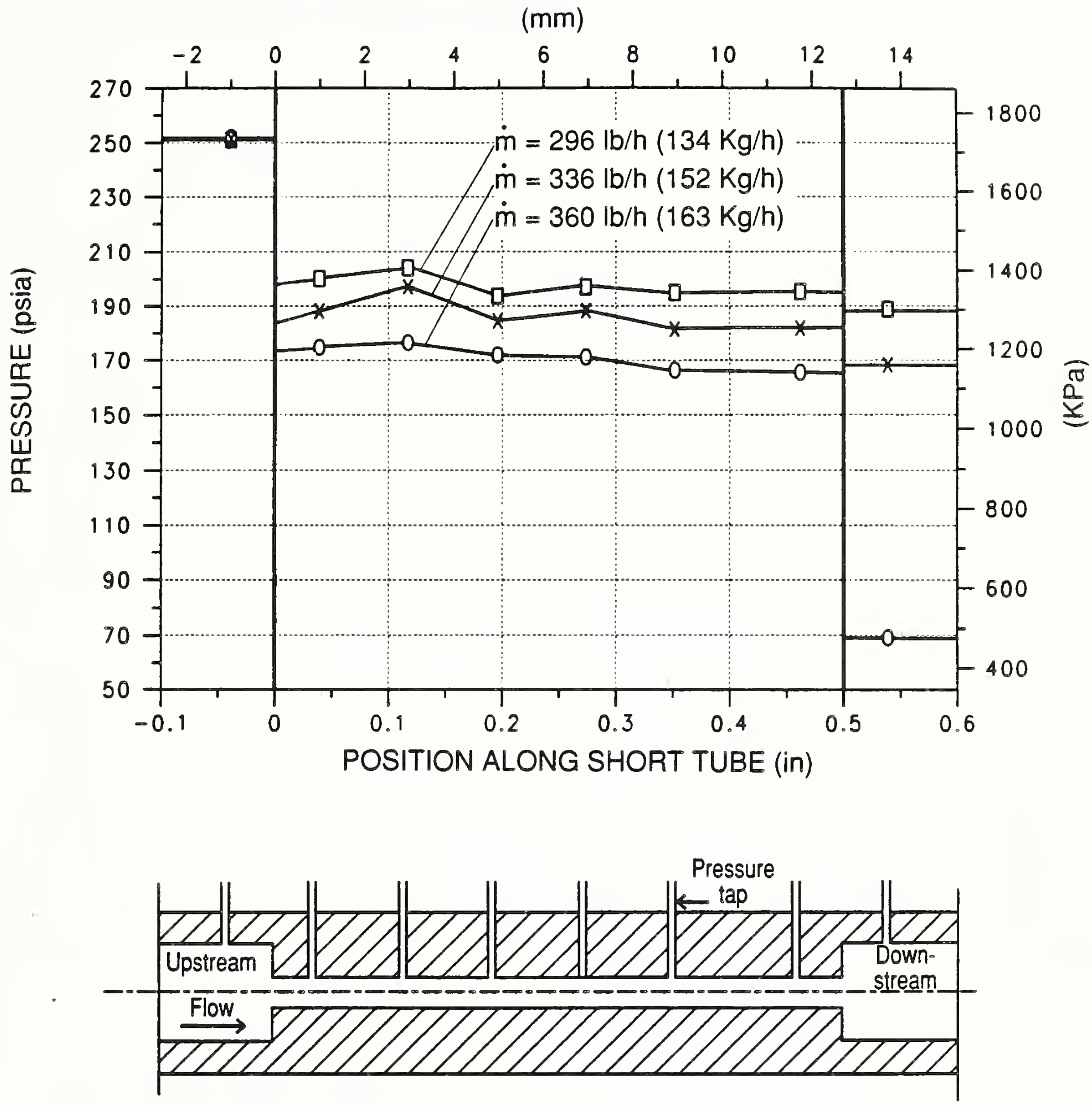

Figure 13. Pressure profile at various downstream pressures with constant upstream conditions. Conditions: L=0.5 in (12.7 mm), D=0.053 in (1.35 mm), subcooling 25°F (13.9°C)

yet enough known to give an absolute meaning to sonic velocity in a separated two-phase fluid. Collins [20] suggested that part of the fluid inside the short tube may be supersonic. If one assumes the flow is truly separated, then different sonic velocities will exist for each phase. The vapor phase

could be choked while the liquid may be traveling supersonic with respect to the vapor while subsonic with respect to itself. The assumption of separated two-phase flow adds the complexity that the cross sectional area changes for each phase along the tube length. The assumption of ideally separated two-phase flow is the opposite extreme from that of homogeneous two-phase fluid. The flow would be most difficult to analyze if it were between these two assumptions.

If one assumes homogeneous two-phase flow, then as quality increases, the sonic velocity increases [24]. It would then be possible to conclude that the sonic velocity is partially dependent upon the downstream pressure. For instance, when the downstream pressure is reduced, the pressure everywhere inside the short tube also reduces, see Figure 13. Thus the quality, sonic velocity and hence mass flow rate all increase. Therefore, the refrigerant velocity may actually be sonic but when the downstream pressure changes, the choking condition, namely the sonic velocity, changes. Changing the choking condition is only possible if the downstream pressure waves are able to propagate upstream.

Choking could occur at the exit plane or immediately outside the exit plane as suggested by Zaloudek [16] and Krakow and Lin [23]. Figure 13 supports the conclusion that choking occurs at or near the exit plane. For example, choked and non-choked flow both exhibit similar inlet pressure drops. However, non-choked flow will not display a large drop in pressure near the exit plane as evidenced by Figure 13.

8. VISUAL RESULTS FROM THE EXPERIMENTATION

Photographs from the visual study are presented in Figures 14 and 15. Figure 14 shows the onset of flashing when downstream pressure closely approximates the liquid saturation pressure referenced to the upstream subcooled liquid temperature, P_{sat}. Observe that subcooled liquid exists on both sides of the short tube. The existence of flashing fluid exiting the short tube and recondensing into a subcooled liquid indicates that the downstream pressure is higher than P_{sat}. Therefore, the flashing process must originate inside the short tube. Although the inside of the tube cannot be viewed from the figure, Pasqua [19] has shown that flashing does originate inside the tube just after the entrance plane.

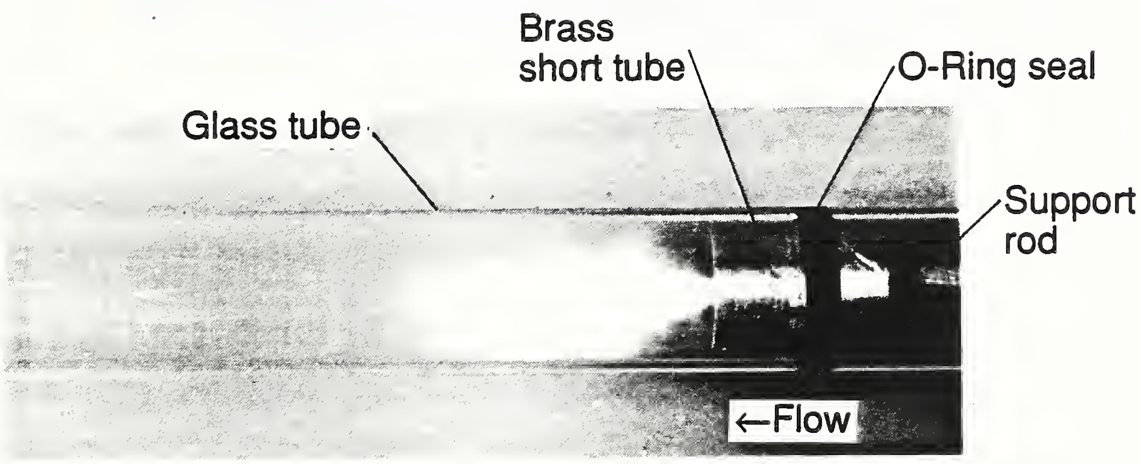

Figure 14. Photograph of short tube showing the onset of flashing. P_1=250 psia (1723 kPa), P_{down}=178 psia (1227 kPa), P_{sat}=177.3 psia (1222 kPa), subcooling 25°F (13.9°C).

Figure 15 shows conditions at typical heat pump operating pressures and temperatures. As the downstream pressure was reduced, the misty jet issuing from the short tube exit grew in size. The misty jet of fluid appeared to be microscopic bubbles suspended in the liquid phase. The misty jet completely filled the exit tube for several inches and appeared to be homogeneous in the respect that a separated phase could not be detected until further down the exit tube. The refrigerant approached a more stable two-phase annular flow as the refrigerant progressed away from the short tube outlet.

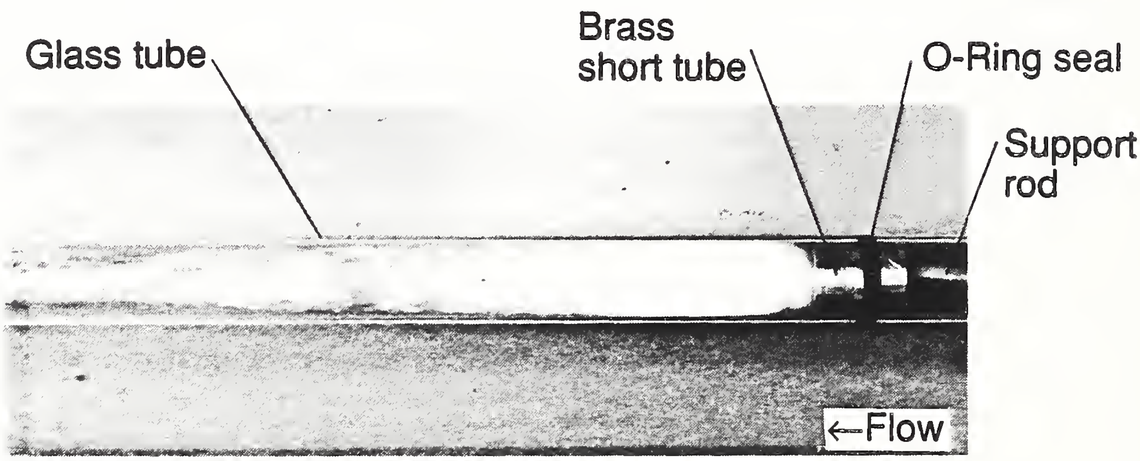

Figure 15. Photograph of short tube at typical heat pump operating conditions. P_1=250 psia (1723 kPa), P_{down}=91 psia (627 kPa), subcooling 25°F (13.9°C).

The pressure profile study indicated that reduction of downstream pressure was felt throughout the entire short tube, thus the state of the fluid inside the short tube in Figure 14 must be different than for the conditions in Figure 15. Pasqua's photographs [19] showed that the density of bubbles inside the short tube increased with reduction in downstream pressure. This supports the theory that the downstream pressure can affect the quality and sonic velocity of the fluid inside the short tube.

9. MASS FLOW RATE DEPENDENCY UPON UPSTREAM SUBCOOLING

Figure 16 shows results of the mass flow rate as a function of the upstream subcooling at three different upstream pressures. The mass flow rate is directly proportional to the degree of upstream liquid subcooling. The slope of each approximately linear curve is slightly dependent on the upstream pressure and as the subcooling increases the lines tend to diverge.

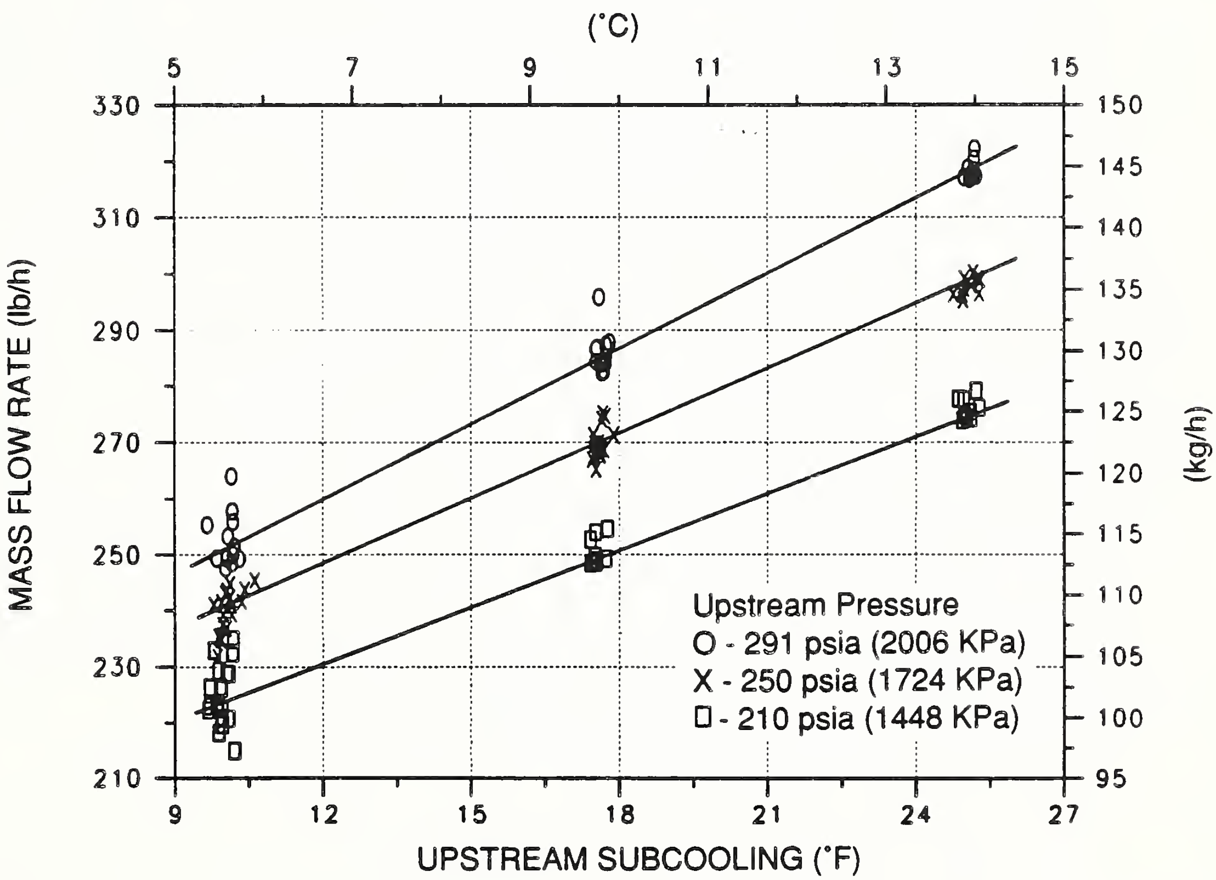

Figure 16. Mass flow dependency upon upstream subcooling. Conditions: L=0.5 in (12.7 mm), D=0.053 in (1.35 mm), $P_{down} < P_{sat}$.

There are two separate effects which occur when subcooling is increased, both of which tend to increase the mass flow rate. First, since fluid density is primarily a function of temperature for subcooled liquids, increasing the degree of subcooling increases the upstream fluid density. Therefore, the overall mean density of the fluid throughout the short tube is increased which permits a higher mass flow rate.

The second effect caused by raising the subcooling is an increase in the pressure drop allowed before the fluid flashes and subsequently chokes. This can best be explained showing the expansion process on a pressure-enthalpy (P-H) diagram, Figure 17. The pressure axis is not presented in logarithmic form, as would typically be found in reference books, because the physical interpretation becomes distorted on a logarithmic scale. The P-H diagram, with constant subcooling lines, is drawn to scale for R-22 using information from [28].

Referring to Figure 17, follow a constant pressure line in a direction of increased subcooling, point X to point A. Observe an increase in the distance between the constant subcooled pressure and the liquid saturation pressure referenced to the upstream subcooled liquid temperature, P_{sat}. For example, $(P_A - P_B) > (P_X - P_Y)$, yet the total pressure drop across the short tube, $(P_A - P_C)$ and $(P_X - P_Z)$, is constant.

This larger allowable subcooled pressure drop, before the fluid flashes, has a larger effect on the mass flow rate than does the increase in upstream fluid density because once the flashing pressure is reached, the fluid becomes approximately choked. This point is further clarified in the next section.

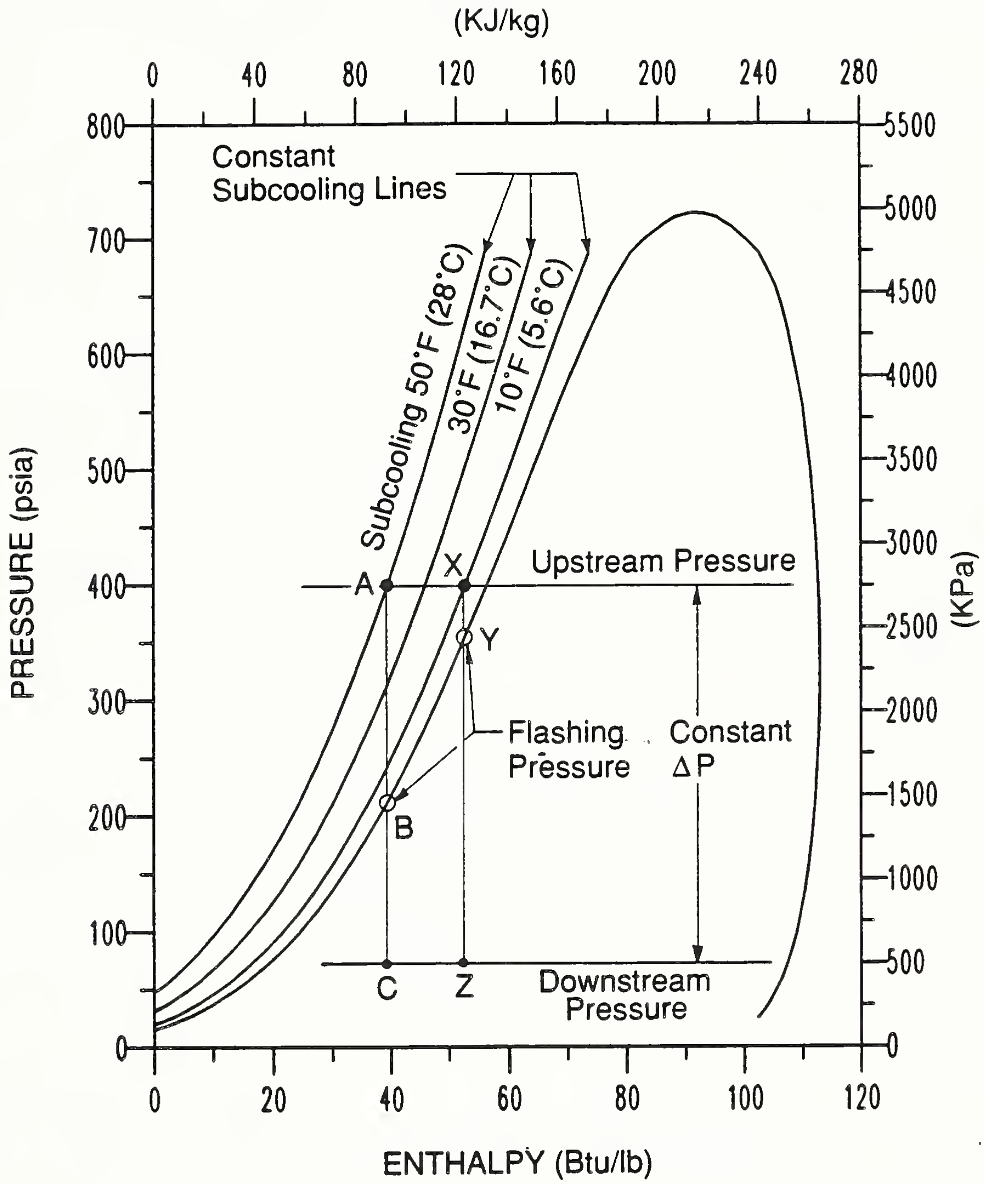

Figure 17. Pressure-enthalpy diagram for R-22 illustrating the effect of changing the subcooling at constant upstream pressure. (Note the pressure axis is not logarithmic.)

For constant upstream and downstream pressures, the subcooling was varied and the pressure profile and mass flow rate were measured. The results are presented in Figure 18. Clearly, the pressure at the short tube inlet

decreased as subcooling increased. Thus, an increase in subcooling increases the mass flow rate and is characterized by a larger subcooled pressure drop just before the short tube inlet.

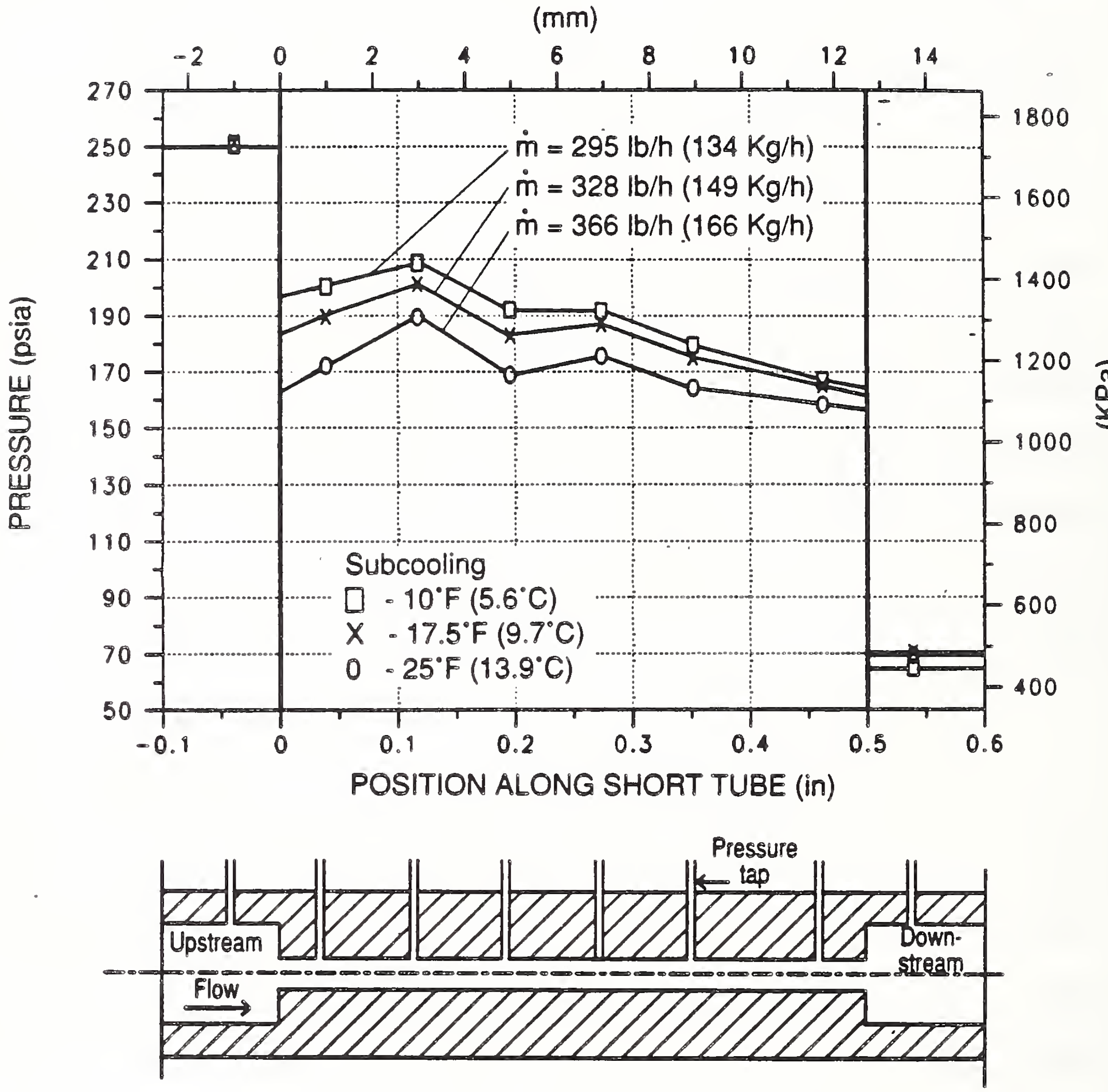

Figure 18. Pressure profile for three different upstream subcooling levels. Conditions: L=0.5 in (12.7 mm) D=0.053 in (1.35 mm).

An important finding from Figure 18 is that at each subcooling level, the pressure inside the short tube approximated P_{sat}. This agrees with Zaloudek's [16] observations and is used later for the formulation of a flow model. It

is conjectured that the pressure inside the short tube remains fairly constant because the flashing process does not have enough time to run to completion inside the short tube. This suggests that there is some degree of liquid metastability present.

Figure 18 also shows that the pressure drop inside the tube increases as subcooling decreases, regardless of the smaller mass flow rate associated with smaller subcooling levels. A higher pressure drop with lower subcooling results because two-phase flows at higher quality exhibit a larger pressure drop.

Referring again to Figure 16, the data scatter increased as the subcooling was decreased. During the testing, it was observed that for inlet subcooling below approximately 10°F (6°C) the liquid line temperature would fluctuate sinusoidally with time. For subcooling near zero, the flow would tend to modulate between subcooled flow to two-phase flow at the short tube inlet. It is not definite that the flow is less stable at lower subcooling levels because a feedback may have been amplified in the experimental loop which may not be amplified in normal systems. However, short tube flow instability has been observed in other experiments where the inlet subcooling was very low [32].

10. MASS FLOW RATE DEPENDENCY UPON UPSTREAM PRESSURE

Figure 19 shows results of mass flow rate as a function of the upstream pressure at three different levels of upstream subcooling. The mass flow rate is directly proportional to the upstream pressure. The slope of each approximately linear line is slightly dependent on the upstream subcooling and, as the upstream pressure increases, the lines tend to diverge. Again, observe the data scatter increase as subcooling decreases.

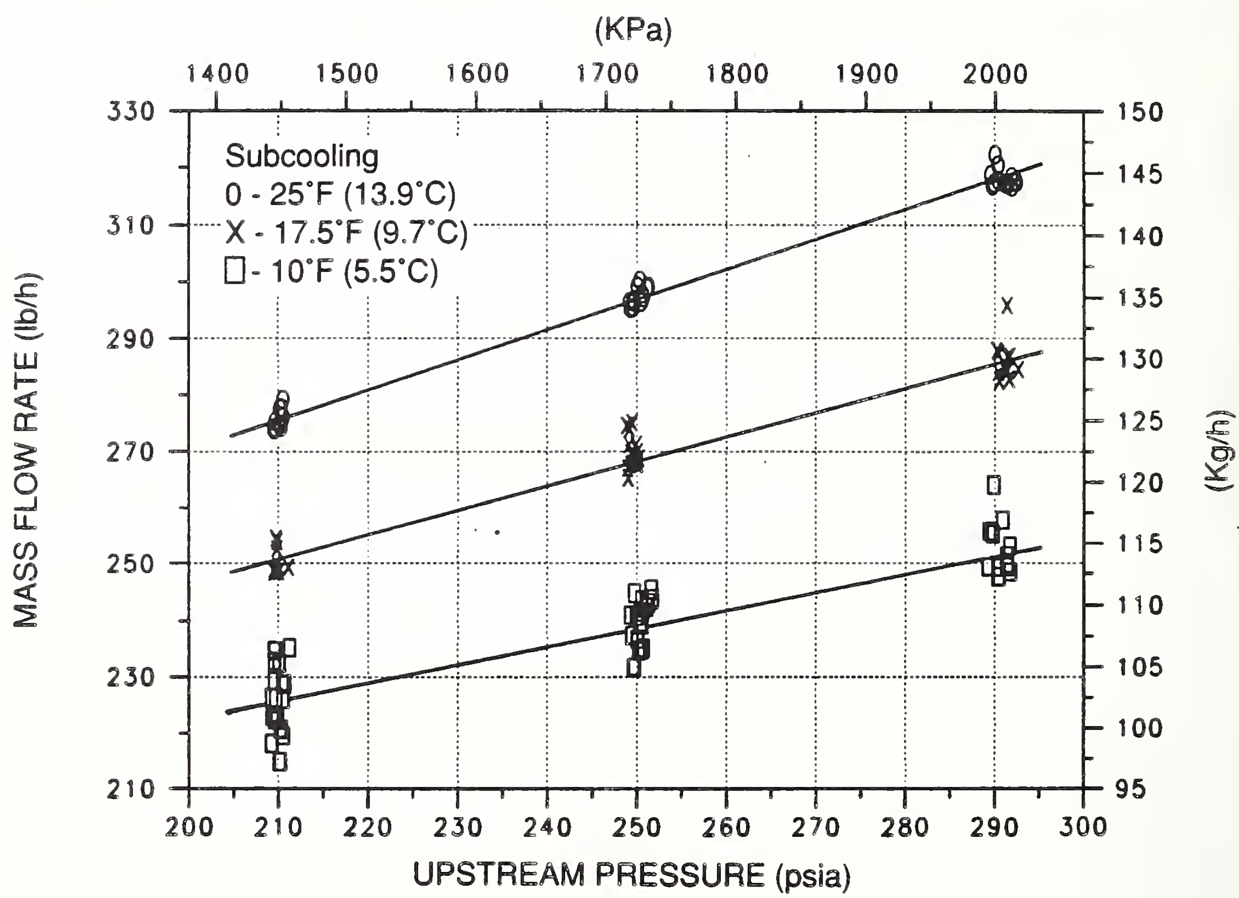

Figure 19. Mass flow rate dependency upon upstream pressure. Conditions: L=0.5 in (12.7 mm), D=0.053 in (1.35 mm), $P_{down} < P_{sat}$

There are two effects which occur by keeping the subcooling constant while raising the upstream pressure. The expansion process is again drawn on the P-H diagram in Figure 20.

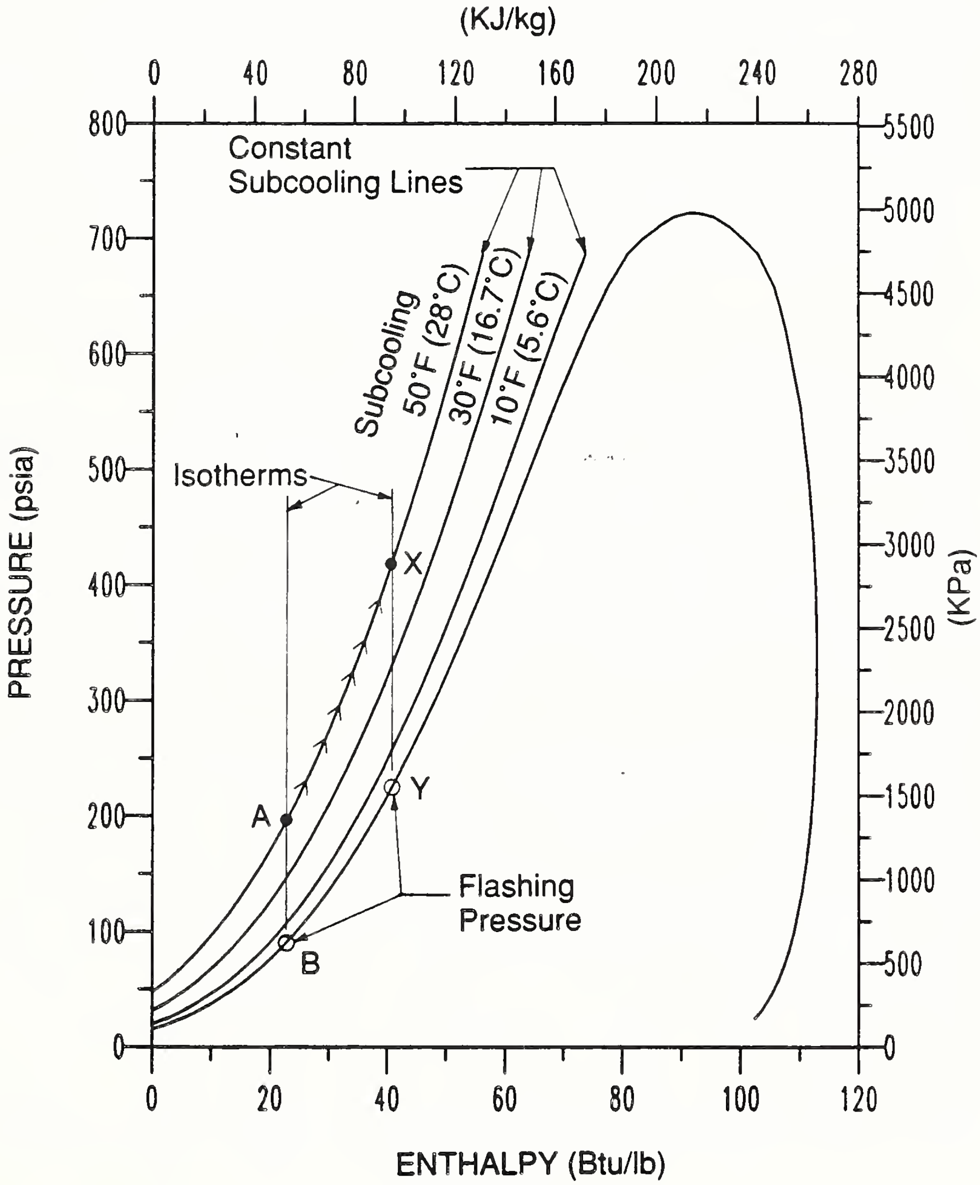

Figure 20. Pressure-enthalpy diagram for R-22 illustrating the effect of changing the upstream pressure at constant subcooling.

Following a constant subcooling line in a direction of increasing pressure, from point A to point X, shows the first effect is an increase in upstream liquid temperature, $T_X > T_A$. Thus, the upstream liquid density must decrease. This tends to decrease the mass flow rate through the short tube.

The second effect caused by increasing the upstream pressure with constant subcooling is an increase in the available pressure drop before the flashing pressure is reached, see Figure 20. For example, $(P_X - P_Y) > (P_A - P_B)$. This tends to increase the mass flow rate through the short tube because, once the flashing pressure is reached, the fluid becomes approximately choked.

The overall effect of increasing the upstream pressure with constant subcooling is to increase the mass flow rate as evidenced from the experimental data in Figure 19. Therefore, one can conclude that the upstream liquid density has less effect on the flow rate then does the available pressure drop before flashing and subsequent choking occur.

For a constant degree of subcooling, a fluid at a higher initial pressure will permit a higher mass flow rate because a more dense fluid will be passing through the short tube, even though the initial fluid density is lower.

11. MASS FLOW RATE DEPENDENCY UPON SHORT TUBE LENGTH

Figure 21 shows the mass flow rate as a function of short tube length for three different diameters. As tube length was increased from 0.5 in (12.7 mm) to 1.0 in (25.4 mm), the change in flow rate was small compared to when it is was decreased from 0.5 in (12.7 mm) to 0.375 in (9.53 mm). This suggests that the flow may be changing to another flow regime for smaller lengths or L/D ratios. It has been shown that for L/D < 3 there is a transition in the flow [5,6]. In the limit, when L/D ≈ 0, a critical downstream pressure does not exist for normal operating conditions [7].

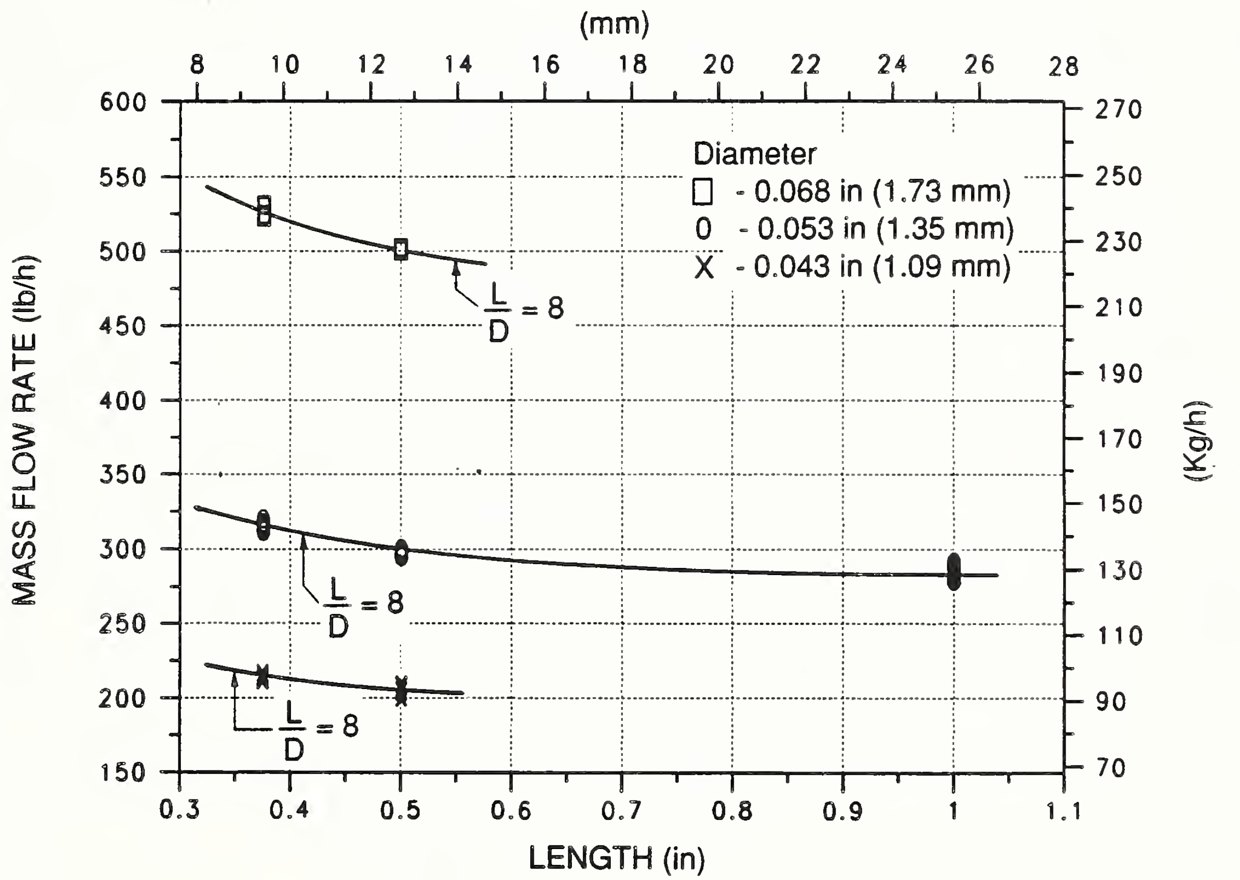

Figure 21. Mass flow rate dependency upon short tube length for three different diameter short tubes. Conditions: P_i=250 psia (1724 kPa), subcooling 25°F (13.9°C), $P_{down} < P_{flash}$

As tube length decreases, the fluid has less time to flash and a corresponding larger liquid core, larger mean fluid density, and a larger mass flow rate result. If the length is decreased enough, the flow would revert to orifice flow where the fluid does not flash until after exiting the tube [7] and the flow becomes dependent upon the downstream pressure.

There seems to be no direct link between the mass flow rate and the L/D parameter. Figure 21 shows where L/D = 8 for three different diameter and three different length short tubes. From the large difference in mass flow rates, one may conclude that the L/D parameter cannot be used to specify mass flow rate. However, for a selected diameter, the L/D ratio may be viewed as a non-dimensional friction factor.

The L/D parameter may be useful to a manufacturer to insure the flow remains choked. For example, a constant flow area expansion device should be insensitive to the downstream pressure, otherwise system performance and reliability would suffer. Maintaining L/D greater than a predetermined cutoff value would help insure the flow remains choked. The smallest L/D ratio tested in this investigation was L/D = 5.5. For this and all larger L/D combinations tested, the flow always exhibited a choked behavior, providing the downstream pressure was less than the liquid saturation pressure, P_{sat}. Thus, results from this experimentation suggest that keeping L/D > 5 would insure a choked flow condition. This limit, however, should be further explored in order to obtain a minimum safe L/D ratio.

There is some information lost by plotting the experimental data with such a wide range of mass flow rates. Figure 22 shows the results for only the

0.053 in (1.35 mm) diameter short tube. The effect of decreasing the length seems more drastic on this scale. It may be concluded that the flow becomes more sensitive to the length when the L/D ratio falls below approximately ten.

Other information lost by squeezing data on a large y axis is data scatter. Clearly the data scatter is more visible when the y axis is expanded. The data is approximately ± 2% from an average value. Some of this scatter is due to the downstream pressure being allowed to vary in the data which is plotted.

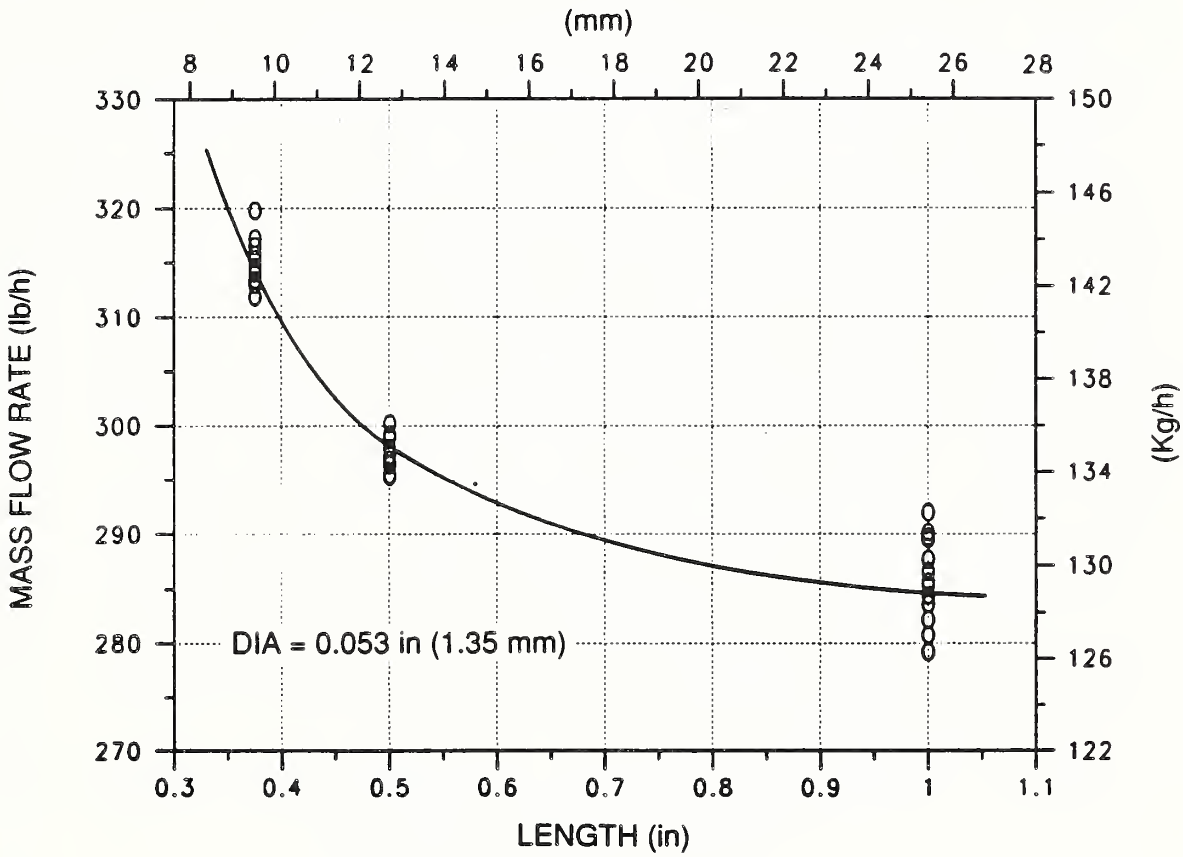

Figure 22. Mass flow rate dependency upon short tube length for a 0.053 in (1.35 mm) diameter short tube. Conditions: P_i=250 psia (1724 kPa), subcooling 25°F (13.9°C), $P_{down} < P_{sat}$.

12. MASS FLOW RATE DEPENDENCY UPON SHORT TUBE DIAMETER

Figure 23 shows the mass flow rate as a function of short tube diameter. Comparing the relative change in mass flow rate with the other parameters demonstrates that the flow rate is most dependent upon the tube diameter. The experimental data was correlated to the equation $\dot{m} = C_1 \cdot (D)^{C2}$, where C_1 was an arbitrary coefficient and C_2 was an arbitrary exponent. Exponent C_2 was found to be 2.11 for sharp-edged short tubes and 2.02 for chamfered inlet short tubes. This result shows that the flow is directly proportional to the short tube cross sectional area.

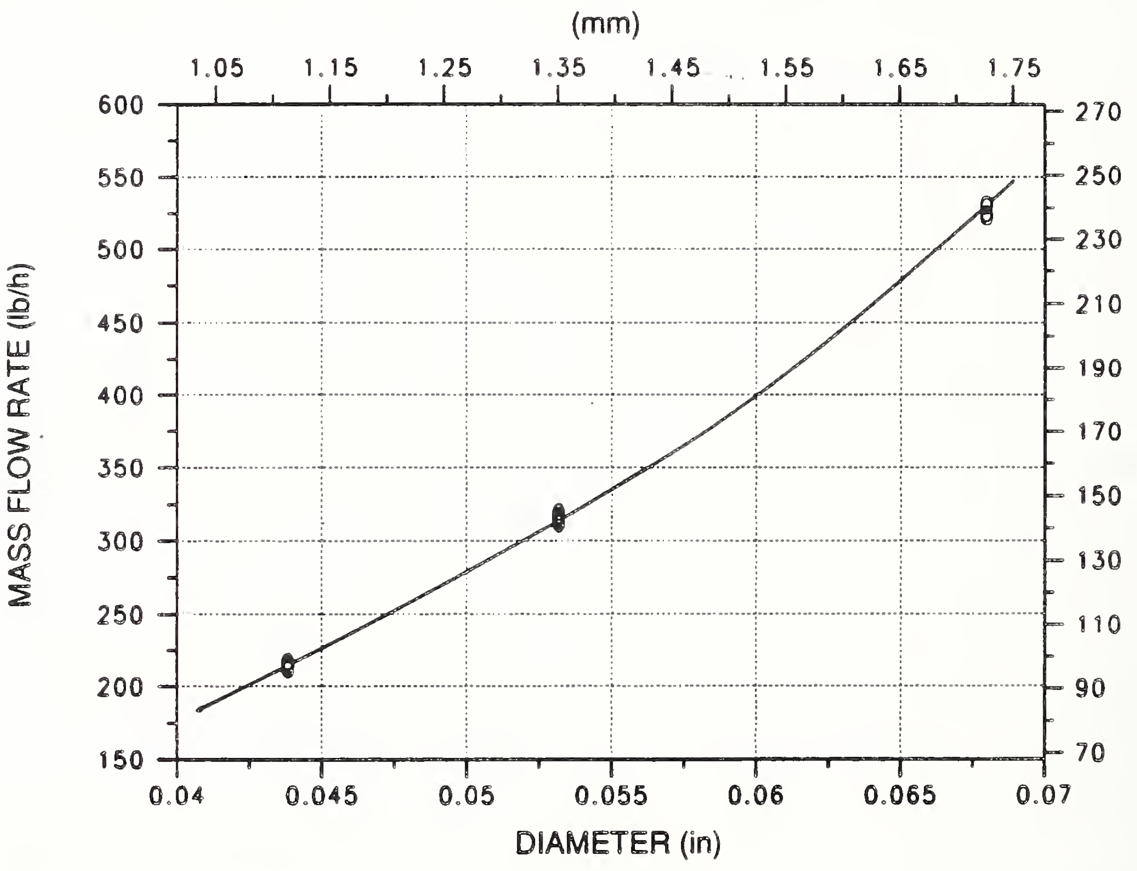

Figure 23. Mass flow rate dependency upon short tube diameter. Conditions: P_1=250 (1724 kPa), subcooling 25°F (13.9°C), $P_{down} < P_{sat}$, L=0.375 in (9.5 mm).

13. MASS FLOW RATE DEPENDENCY UPON INLET AND EXIT CHAMFERING

Figure 24 shows mass flow rate as a function of inlet chamfering depth. For the short tubes tested, the flow rate increased from 5 to 25% depending on the chamfer depth and the L/D ratio. Flow dependency to inlet chamfering was partially dependent on the short tube L/D ratio in that larger L/D ratio short tubes displayed more dependency to inlet chamfering. Commercially available short tube restrictors inspected by the authors had chamfer depths on the order of 0.01 in (0.25 mm) or had no chamfer at all.

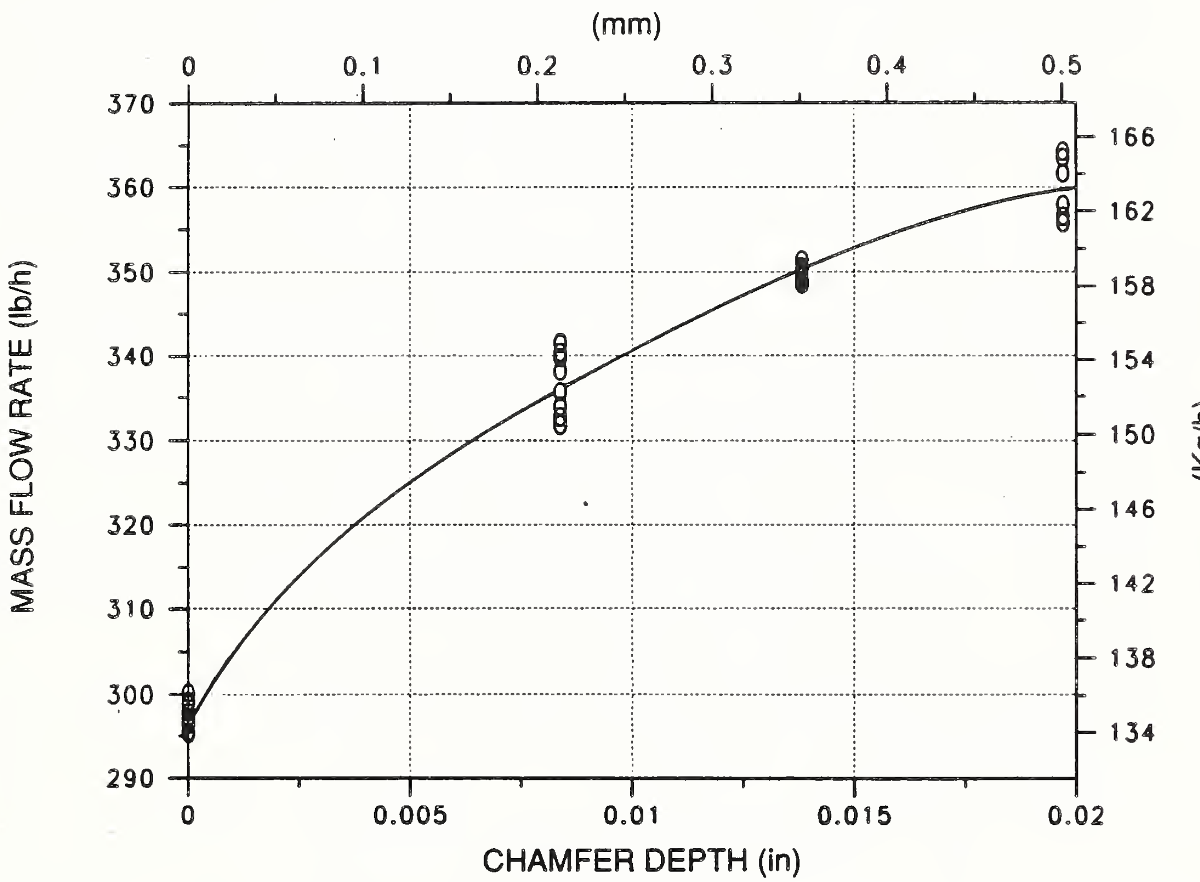

Figure 24. Mass flow rate dependency upon inlet chamfering. Conditions: P_1=250 psia (1724 kPa), subcooling 25°F (13.9°C), $P_{down} < P_{sat}$, L=0.5 in (12.7 mm), D=0.053 in (1.35 mm), chamfer angle 45°.

Sharp edged and chamfered short tubes can be compared to sharp edged orifices and nozzles. Flow through tubes with smooth entrances exhibit less entrance losses and hence allow higher flow rates. For a short tube of a given length, chamfering the inlet allows less entrance turbulence thus a higher subcooled pressure drop and higher mass flow rate result.

Results from the experimentation showed that chamfering the exit of the short tube had no appreciable effect on the mass flow rate. This finding suggests that the large pressure drop at the short tube outlet is due more to the choking phenomena than due to exit losses.

14. DERIVATION OF THE SHORT TUBE FLOW MODEL

A flow model for initially subcooled R-22 flowing through short tubes with $5 < L/D < 20$ is derived in this section. Simplicity of the model and accuracy of mass flow rate prediction were the two main criteria used in the model formulation. Throughout this chapter, the liquid saturation pressure referenced to the upstream subcooled liquid temperature will be abbreviated as P_{sat}. The derived mass flow rate model applies to the choked flow condition that $P_{down} < P_{sat}$.

Observation that the flow was approximately choked, as long as the downstream pressure was lower than P_{sat}, indicated that a critical flow model would be appropriate to describe the flow. This condition is prevalent for typical heat pump applications in both the heating and cooling modes. With a critical flow analysis, all of the fluid properties must be known in the region where choking occurs. Because the fluid in the short tube has been observed to be in a separated two-phase condition, [3,5,6,16,19], the fluid quality, temperature, and sonic velocity inside the short tube could not be successfully predicted. Thus, a critical flow model based on sonic velocity could not be derived.

The inlet pressure, downstream pressure, and inlet subcooling are parameters which are usually known or specified when designing a system. Using these design parameters and observing that the pressure inside the short tube approximated P_{sat} dictated use of a modified orifice equation. To use the orifice equation, the assumptions used to derive it must first be accepted.

The orifice equation and its assumptions [8] are listed below:

$$\dot{m} = C \cdot A_o \cdot [\ 2 \cdot \rho \cdot g_{ca} \cdot (P_1 - P_2) \ / \ (1-\beta^4)\ ]^{1/2} \tag{1}$$

Assumptions: flow is adiabatic,

flow is isothermal,

flow is incompressible,

potential effects are negligible,

fluid performs no external work,

flow is steady with uniform velocity profile.

Drawing an arbitrary control volume around the short tube, as in Figure 25, shows that the assumptions above are clearly violated.

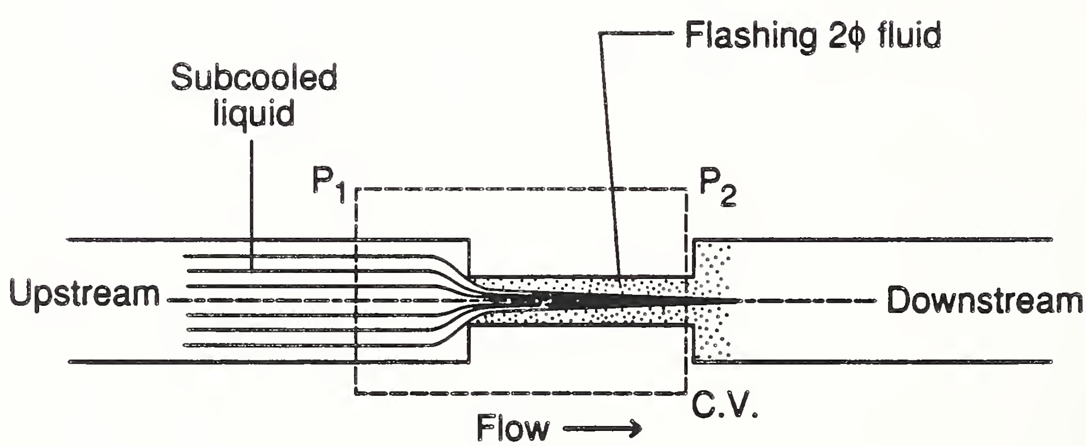

Figure 25. Arbitrary control volume for the short tube.

The fluid has been observed to be two-phase inside the short tube [19], therefore, the assumption of incompressible flow is violated. The temperature

along the short tube changed typically from 113°F (45°C) at the inlet to 40°F (5°C) at the outlet. Thus, assumption of isothermal flow is violated. Even if these assumptions were not violated, fluid properties would be difficult to predict near the tube exit.

The control volume drawn in Figure 26 is more compatible with the orifice equation assumptions.

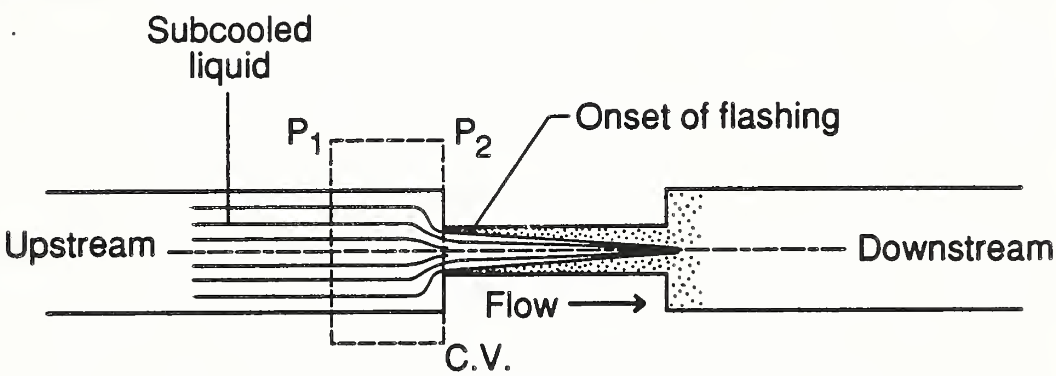

Figure 26. Control volume drawn about the upstream and inlet planes.

As long as the edge of the control volume is drawn before flashing occurs, then the fluid remains in a liquid phase. The fluid temperature at the short tube inlet was observed to be near the upstream liquid temperature. In addition, the pressure at the short tube inlet was observed to be near P_{sat}. Both of these observations support the assumption of isothermal flow within the drawn control volume. If the temperature is constant and the fluid has not yet flashed, then the fluid may also be assumed incompressible. The assumption of adiabatic flow is justified because there is very little outside surface area on the short tube for heat transfer to occur. This is opposed to the situation where a capillary tube is directly soldered to the

liquid line for instance. There are negligible potential effects because of the small change in elevation, even if the short tube flow is vertical. There is no external work performed by the fluid in the control volume. Because the fluid remains in the liquid state, as opposed to a separated two-phase fluid, the velocity profile may be assumed steady and flat as long as the upstream tube conditions remain steady and turbulent.

Once the assumptions were accepted, the orifice equation was modified for short tube flow. The $(1-\beta^4)$ term was dropped from the equation because the ratio of the short tube diameter to the upstream pipe diameter (for short tubes used in heat pumps) raised to the fourth power is negligible when compared to one. The coefficient of discharge is defined as the actual mass flow rate divided by the theoretical mass flow rate. Therefore, the coefficient of discharge was set equal to unity until such time as it is empirically adjusted.

Because a choking phenomena was observed and the pressure inside the short tube approximated P_{sat}, P_{sat} was selected to replace the downstream pressure in the model. If P_{down} were used, assumption of incompressible flow would be violated. Using P_{sat} instead of P_{down} forms a critical flow model by using the pressure obtained just as the fluid is choked as opposed to using the sonic velocity to predict the critical pressure. The updated model becomes:

$$\dot{m} = C \circ A_s \circ [\ 2 \circ \rho \circ g_{ca} \circ (P_1 - P_{sat})\ ]^{1/2} \tag{2}$$

Two approaches were used to empirically correct the model. Initially, the coefficient of discharge was set equal to a function of the parameters

governing the flow through the short tube. This approach did not satisfy the boundary condition that there is still fluid flowing at zero degree subcooling, for example $P_{sat} = P_{1,}$ thus the model would predict zero mass flow rate at zero subcooling. This approach was abandoned and the coefficient of discharge was set equal to unity and dropped from the equation.

The second approach was to empirically adjust P_{sat} as a function of the parameters. The experimental saturation pressure, P_2, was calculated using the measured parameters and solving equation (2) for P_{sat}. The difference between the experimentally calculated P_2 and P_{sat} is called the correction pressure, and is shown in Figure 27.

Observe the linear relationship between the correction pressure and subcooling. At approximately 10°F (5.6°C) subcooling, P_{sat} is within a few percent of the experimentally calculated P_2 and very little correction is needed. As subcooling decreases towards zero, one must add a negative correction pressure to P_{sat}. For example, (P_1-P_{sat}) begins to under-predict the mass flow rate. This result may be attributed to the effects of liquid metastability because the fluid is expected to flash and choke before it actually does.

As subcooling increases above 10°F (5.6°C), (P_1-P_{sat}) begins to over-predict the mass flow rate; one must add a correction pressure to P_{sat}. This result indicates that the pressure drop caused from area contraction and fluid acceleration exceeds the available subcooled pressure drop before the fluid flashes.

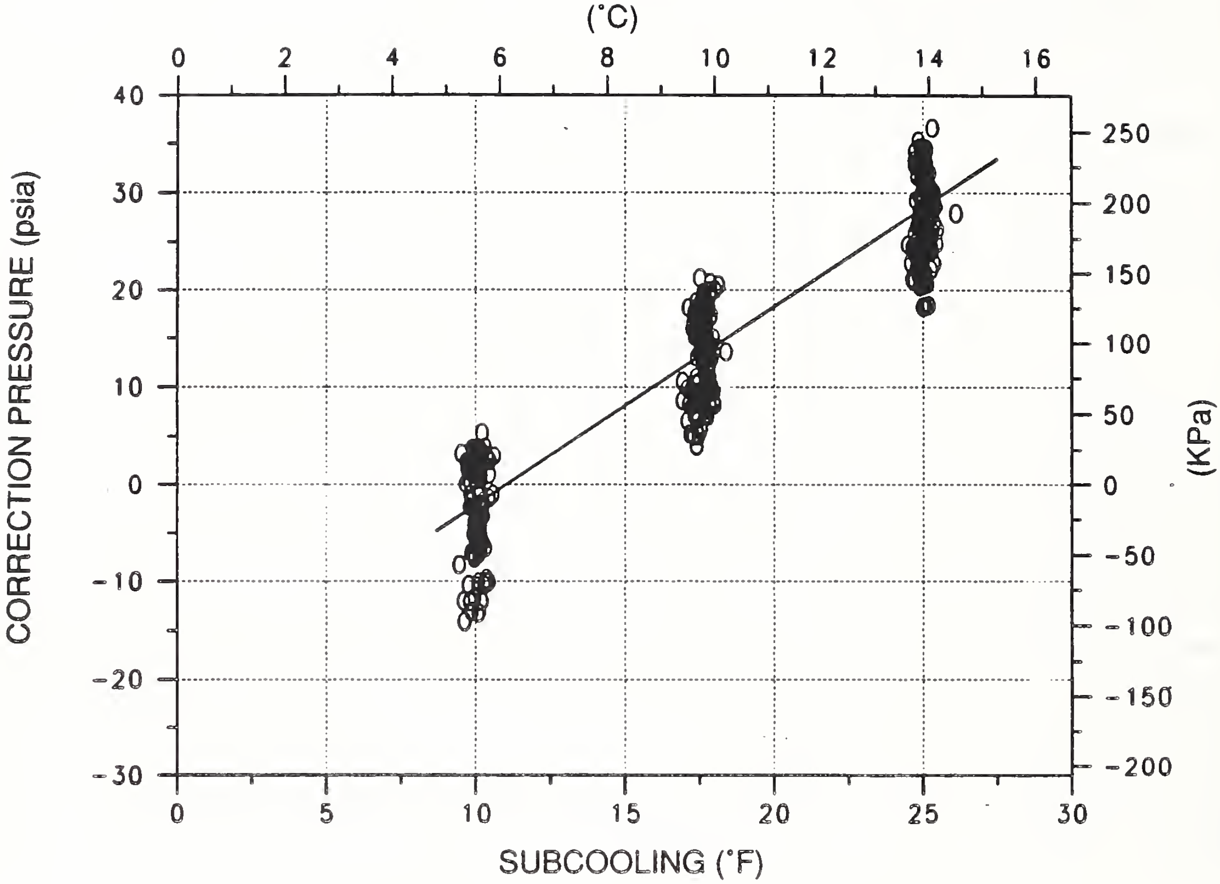

Figure 27. Correction pressure against liquid subcooling. (All sharp-edged data points used in this plot).

The non-dimensional parameter $[(T_{sat} - T_{fluid}) / T_{sat}]$ was chosen to empirically correct P_{sat} as a function of subcooling. T_{sat} refers to the liquid saturation temperature with the upstream pressure at zero degree subcooling; T_{fluid} refers to the subcooled temperature of the entering fluid. A non-dimensional subcooling parameter was chosen for two reasons. First, it allows use of either SI or English units and second, it may be compatible for use with fluids other than R-22. It should be noted that the parameter $(\Delta H/H_{fg})$, a non-dimensional negative quality, did correlate well with the data. This parameter, however, was slightly dependent upon

the upstream pressure which added an extra parameter to the model.

Since the flow was not ideally choked, the correction to P_{sat} must also include the effect of the downstream pressure. The non-dimensional parameter $[(P_{sat}-P_{down})/P_{sat}]$ was used for this purpose. Because the flow is not very sensitive to downstream pressure, specifying the evaporator pressure before or after the evaporator coil in the model makes negligible difference in the mass flow rate.

The short tube length and diameter were found to have separate effects on the correction pressure, however, when correlated combined as the L/D ratio, only a minor penalty, less than a fraction of 1%, resulted. Thus, the L/D ratio was incorporated into the correction function for P_{sat}. It should be noted that the flow rate is not directly related to the L/D ratio. The model has already taken into account the tube diameter in the cross sectional area term, therefore the L/D ratio should be viewed as a parameter which accounts for flow friction. Using a nonlinear regression curve fitting program, the final empirically corrected flow model for sharp-edged short tubes is:

$$\dot{m} = A_s \circ [\ 2 \circ \rho \circ g_{ca} \circ (\ P_1 - P_2)\ ]^{1/2} \tag{3}$$

where:

$$P_2=P_{sat} \circ [1+12.599 \circ (SUB)^{1.293}-0.1229 \circ EXP(-0.017(L/D)^2) \circ 0.04753 \cdot (EVAP)^{0.6192}] \tag{4}$$

$SUB = (T_{sat}-T_{fluid})/T_{sat}$ (T in absolute temperatures)

$EVAP= (P_{sat}-P_{down})/P_{sat}$ (P in absolute pressures)

All the empirical corrections to P_{sat} are non-dimensional, thus SI or English units can be used. Ninety-five percent of the measured data are within ± 5% of the model's prediction. Figure 28 shows a pressure-enthalpy diagram which defines the parameters used in the model.

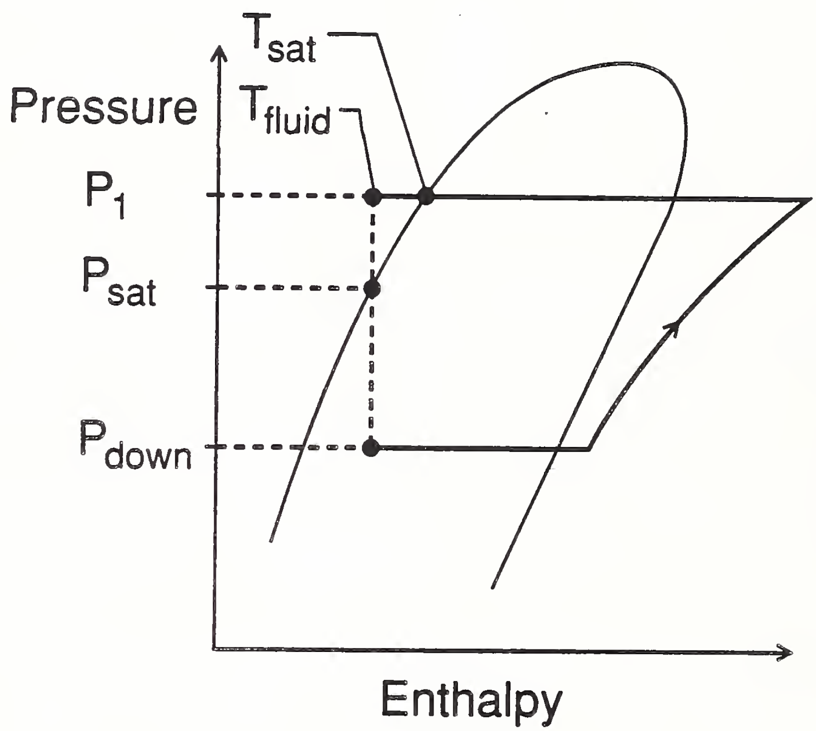

Figure 28. Pressure-enthalpy diagram showing the parameters of the model.

Equation 3 and 4, the sharp-edged model, was kept as the base equation and inlet chamfering was dealt with by deriving a proportional constant. The proportionality constant was derived as a function of chamfer depth and the L/D ratio:

$$C_c = 1 + 0.0551 \cdot (L/D)^{0.5844} \cdot (DEPTH/D)^{0.2967} \quad (5)$$

where:

DEPTH = chamfer depth (45° angle)

Note that when inlet chamfering depth is zero, the correction equation reverts back to sharp edged entrance flow. The final flow model becomes:

$$\dot{m} = C_c \cdot A_s \cdot [\ 2 \cdot \rho \cdot g_{ca} \cdot (P_1 - P_2)\ ]^{1/2} \tag{6}$$

The model is limited to the data range used in its derivation. These limits are shown in Table 3.

Table 3. Limitations for application of the flow model.

		Refrigerant-22		
10°F (5.5°C)	<	Subcooling	<	25°F (13.9°C)
210 psia (1448 kPa)	<	P_1	<	291 psia (2006 kPa)
30 psia (207 kPa)	<	P_{down}	<	liquid saturation
0.375 in (9.5 mm)	<	Length	<	1.0 in (25.4 mm)
0.043 in (1.09 mm)	<	Diameter	<	0.067 in (1.70 mm)
0	<	Chamfer Depth	<	0.02 in (0.508 mm)
		Inlet chamfer angle = 45°		
		Material of short tube: Brass		

The model agrees with the experimental data from Domingorena and Ball [33] as reported in [21]. Eighteen of the twenty-one experimental data from [33] agree with the model within ± 5% with a maximum difference of only 7%. Limited verification of the model was performed for conditions outside those listed in Table 3. For example, the model predicted the mass flow rate for 0-10°F (0-5.6°C) subcooling within ± 2.5% of the experimental results of Mulroy and Didion [34]. This indicates that the limits in Table

3 may be extended within reason. Since the effect of the inlet quality was not studied, zero degree subcooling becomes the limit. Other data from [34] which were within the limits in Table 3 were all within ± 2% of the predictions of the model. The thermodynamic properties of R-22 used in the modeling were calculated using the Carnahan-Starling-DeSantis equation of state presented in reference [35].

In the development of the orifice equation, a uniform, turbulent, flat velocity profile was assumed. Effects such as normal stream turbulence or stream swirling caused by elbows and inlet screens were neglected. Therefore, actual flow rates in the field may vary slightly from the model's prediction due to the effects of installation.

15. MASS FLOW PREDICTION USING FLOW CHARTS

The derived flow model was used to construct mass flow rate prediction charts which may be used for initially subcooled R-22 flowing through short tubes with 5 < L/D < 20. The flow parameters have been extended beyond the limits used in the correlation to what has been assumed a safe limit. Extrapolating beyond the chart values is not advised. Since the flow is essentially choked, the charts were constructed with an assumed evaporator pressure at 91 psia (627 kPa). The charts should provide a predicted mass flow rate within a few percent of the flow model depending on actual evaporator pressure and user reading error. The mass flow rate charts were constructed paralleling the method used in reference [15] for flow through capillary tubes. The following equation is used for flow rate calculations:

$$\dot{m}_a = \dot{m}_r \circ \Phi_1 \circ \Phi_2 \circ \Phi_3$$

where:

$\dot{m}_a$ = actual mass flow rate for short tube,

$\dot{m}_r$ = reference short tube mass flow rate obtained from Figure 29,

Φ_1 = correction factor for tube geometry obtained from Figure 30,

Φ_2 = correction factor for subcooling obtained from Figure 31,

Φ_3 = correction factor for chamfered inlet obtained from Figure 32.

To obtain the mass flow rate, a reader has to first find the reference mass flow rate by finding the intersection of the design upstream pressure and upstream liquid subcooling in Figure 29. Dimensions of the reference short tube are L=0.5 in (12.7 mm) and D=0.053 in (1.35 mm). The geometry correction factor, Φ_1, can be read from Figure 30 by finding the intersection of the length and diameter of the short tube in question.

The correction factor, Φ_2, is needed since mass flow rate dependence on tube geometry is a function of subcooling. If the short tube has an inlet chamfer, then Φ_3 can be read from Figure 32 and be used to correct the mass flow rate.

Again, the charts were constructed with a constant evaporator pressure at 91 psia (627 kPa). For small deviations in evaporator pressure, less than ±20 psia (±138 kPa), chart value error should be less than 1%. For larger deviations in evaporator pressure, application of the model is recommended. To use the charts or the model, the downstream pressure must always be below the liquid saturation pressure referenced to the upstream subcooled liquid temperature, P_{sat}. This stipulation accounts for all typical operating conditions found in the heat pump cycle, whether in the heating or cooling mode.

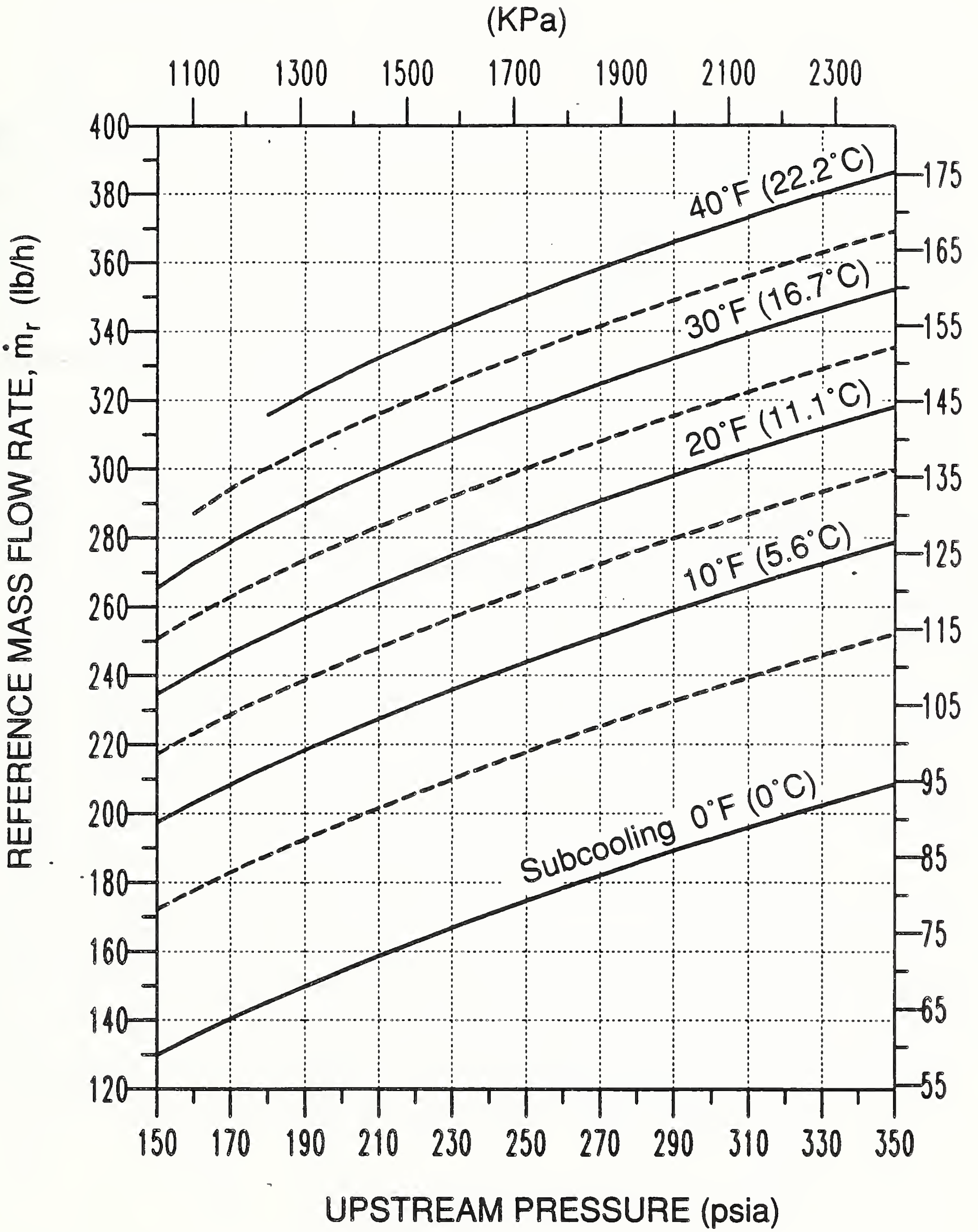

Figure 29. Mass flow rate chart for the reference short tube. L=0.5 in (12.7 mm), D=0.053 in (1.35 mm) with a sharp edged entrance.

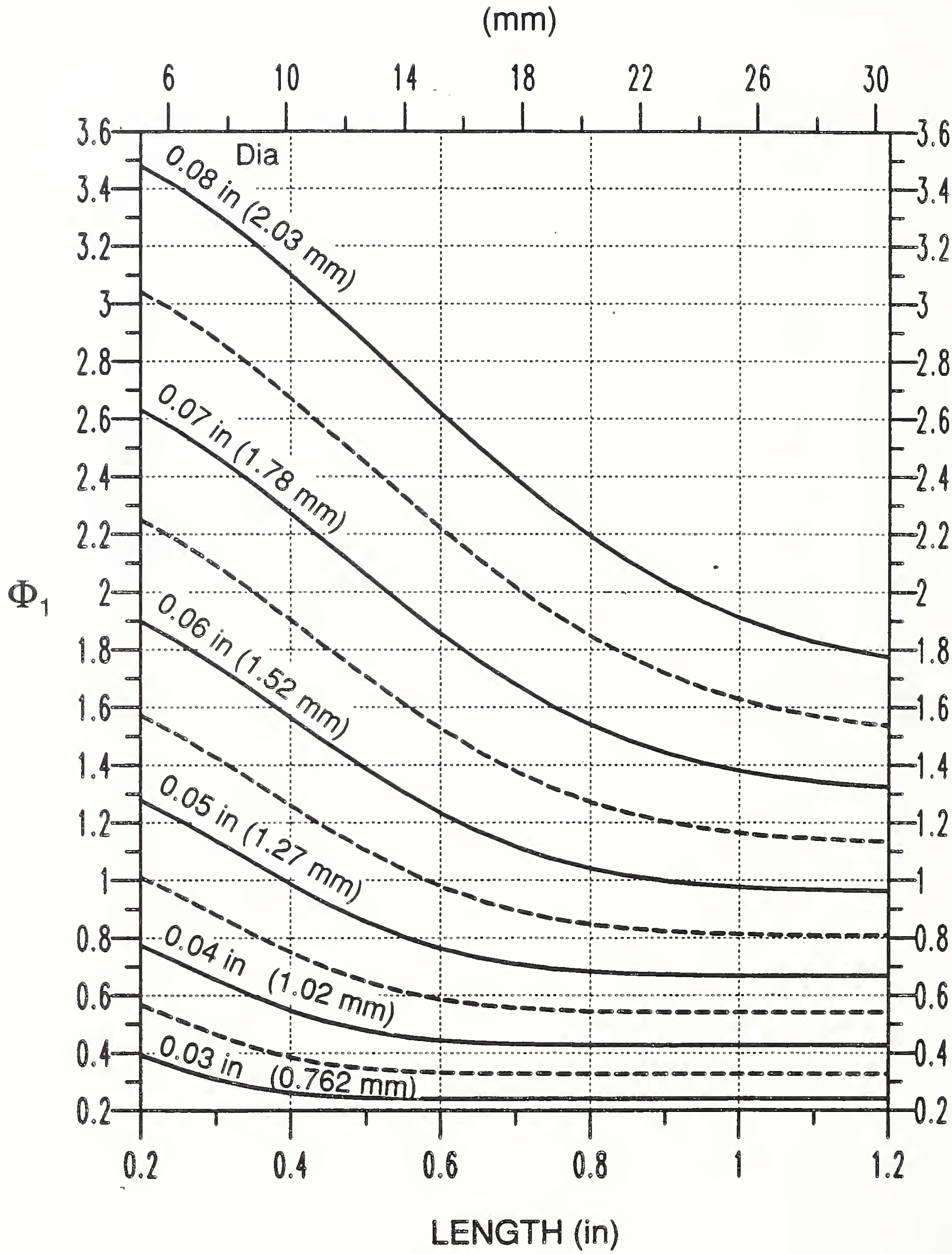

Figure 30. Correction factor for short tube geometry.

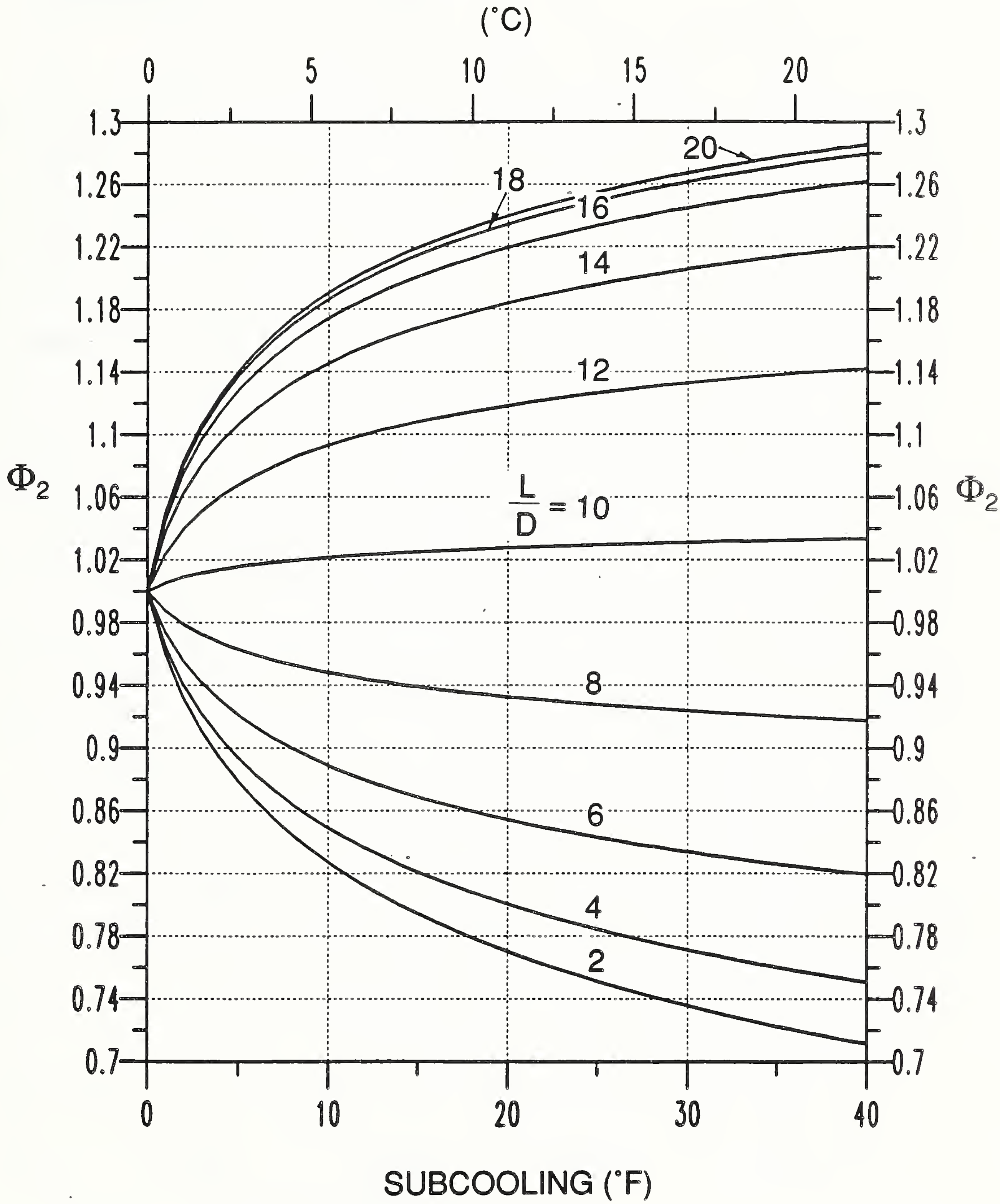

Figure 31. Correction factor for subcooling.

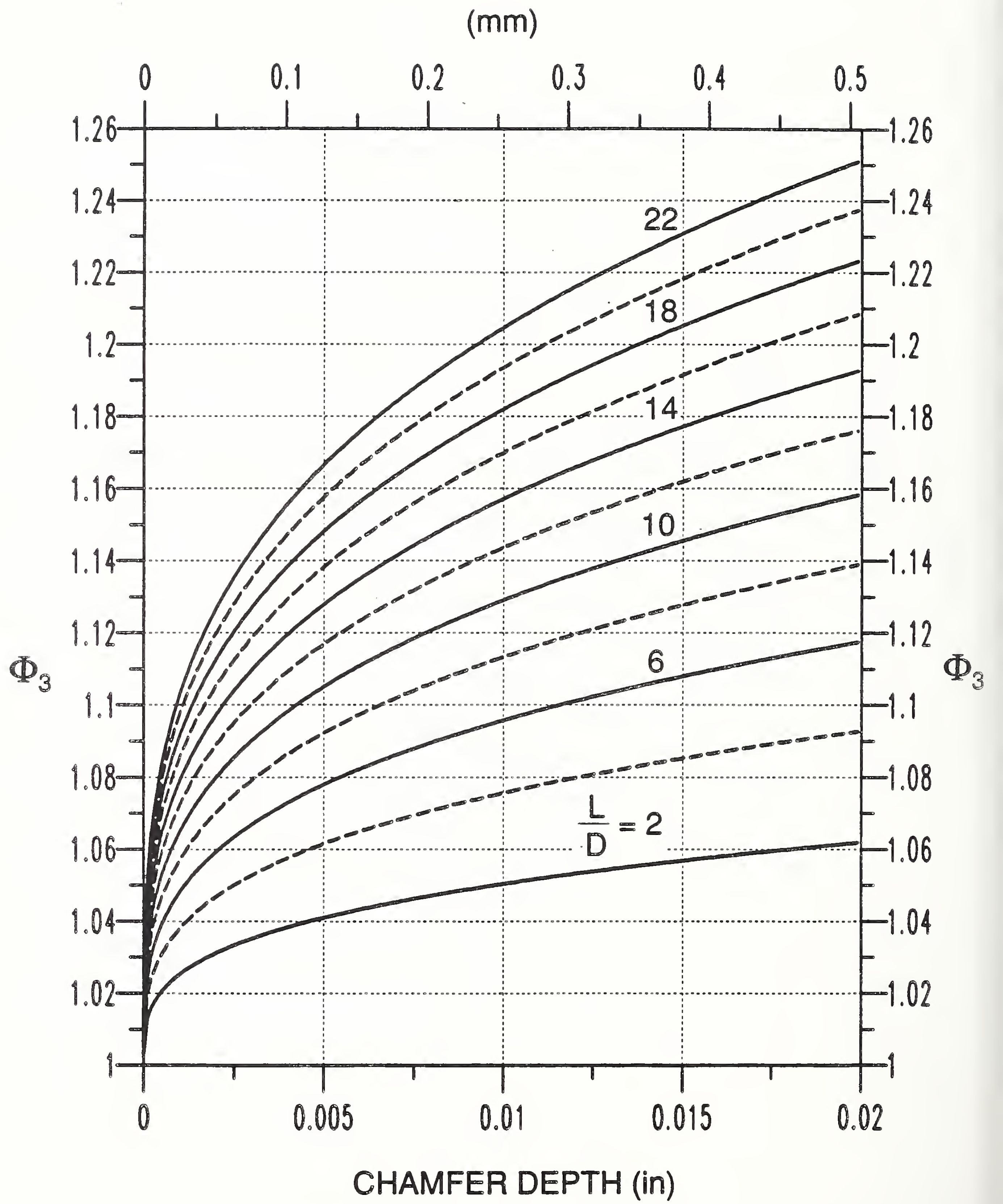

Figure 32. Correction factor for inlet chamfering.

16. CONCLUSIONS

In the first step of this study, previous work on the flow through short tubes was reviewed. Flow charts, such as those used to size capillary tubes, could not be found in the literature. In addition, an acceptable flow model which could predict the mass flow rate through short tube restrictors could not be found. The models available have either a high degree of empiricism associated with them, are too complex, neglect an important parameter(s), apply to different fluids, or apply to a very limited range of operating parameters. Accordingly, experiments were conducted and a semi-empirical flow model and mass flow charts based upon the model were developed. The model predicts 95% of the measured data within ± 5%. The 929 experimental data points used in the correlation process can be found in appendices A and B.

Flow through a short tube restrictor was observed to be approximately choked once the downstream pressure was reduced below the liquid saturation pressure referenced to the upstream subcooled liquid temperature, P_{sat}. This condition applies to typical heat pump applications in both the heating and cooling modes. Choking was not ideal in that an increase in mass flow rate, up to 8%, accompanied further reductions in downstream pressure below P_{sat}. The fact that the flow rate through a short tube is fairly insensitive to downstream pressure allows a short tube restrictor, like a capillary tube, to be successfully employed as an expansion device. Because the flow is choked, specifying the evaporator pressure at the compressor inlet, as opposed to specifying the pressure downstream of the short tube, will introduce a negligible error in the mass flow rate calculation.

A visual study of the flow revealed that a small misty jet (a very densely populated bubbly mixture) quickly recondensed once exiting into the downstream tube when the downstream pressure was near P_{sat}. When the downstream pressure was reduced well below P_{sat}, the misty jet of fluid grew in size and eventually reverted to the more stable two-phase annular flow.

Large changes in pressure were observed at the short tube entrance and exit planes when the downstream pressure was well below P_{sat}. The large pressure drop in the entrance plane was caused by the area contraction and subsequent fluid acceleration. It was concluded that the large pressure drop in the exit plane does dictate that choking, at least non-ideally, has occurred. The pressure level measured inside the short tube was nearly constant and approximated P_{sat}. There was a small pressure drop across the short tube which increased as downstream pressure or subcooling was decreased. It was observed that the pressure everywhere within the short tube varied when the downstream pressure was varied. This finding supports that the flow was never ideally choked.

The flow rate was found to be directly proportional to the upstream pressure. Raising the upstream pressure while keeping the subcooling constant caused two separate effects to occur. First, the upstream liquid density decreased because the fluid temperature increased. This effect tends to cause a decrease in mass flow rate. The second effect caused by raising the upstream pressure was an increase in the available pressure drop between the upstream pressure and P_{sat}. This effect tends to increase the mass flow rate. Because the mass flow rate increased as a result of

these two effects, it was concluded that the available pressure drop before the fluid flashes and subsequently chokes plays a more dominate role in governing the flow rate than the upstream liquid density.

The flow rate was found to be directly proportional to upstream subcooling. Raising the upstream subcooling while keeping the upstream pressure constant increased both the upstream fluid density and the subcooled pressure drop. Both of these effects added to increase the mass flow rate.

The flow rate was found to be inversely proportional to short tube length. For a given tube diameter, as the L/D ratio was reduced below $\approx$ 10, the flow rate began to increase very rapidly. As the L/D ratio was increased above 10, the flow rate became less affected by the change in length. It was concluded that the flow phenomenon begins to revert towards orifice flow, where flashing does not occur inside the tube, when L/D < 10. For all the L/D ratios tested (the smallest tested was L/D = 5.5), the fluid always remained approximately choked. In order to insure that the flow is choked under a large range of operating conditions, it is recommended that for a given diameter, L/D > 5.

The flow rate was found to be directly proportional to the short tube cross sectional area. The flow area was the strongest variable in determining the mass flow rate. For a given tube diameter, the flow rate was limited to a relatively small range of values, regardless of the other parameters.

The mass flow rate was highly sensitive to inlet chamfering. Chamfering the inlet of the short tube caused an increase in the mass flow rate, up to

25%, depending upon the chamfer depth and the L/D ratio. Chamfering the exit of the short tube caused no appreciable change in mass flow rate.

The flow became unstable for subcooling levels below 10°F (5.6°C). This instability may have been due to a feedback in the counterflow heat exchangers or because of the electric heater located in the liquid line.

Although this investigation covered a large percentage of the operating conditions for residential heat pumps, additional research is needed. Two-phase fluid entering the short tube should be analyzed. The model should be applied to experimental data for other fluids and other short tube materials to see what other correlations may be needed. More data is needed to refine the chamfering equation. The effects of oil contamination should be analyzed. More data is needed to provide a minimum safe L/D value which a manufacturer may use to insure the flow remains choked.

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APPENDIX A. EXPERIMENTAL DATA FOR THE SHARP-EDGED SHORT TUBES

TEST	PUP PSIA	PSAT PSIA	PDOWN PSIA	RHO LB/FT3	SUBCOOLING F	LENGTH INCH	DIAMETER INCH	M LB/H
20	249.94	177.14	92.22	73.09	25.0	1.0000	.05330	283.65
20	250.09	176.97	91.53	73.10	25.1	1.0000	.05330	285.64
20	250.19	176.55	91.80	73.13	25.3	1.0000	.05330	279.20
21	249.49	177.57	91.30	73.06	24.7	1.0000	.05330	285.34
21	249.66	177.65	91.37	73.06	24.7	1.0000	.05330	282.20
21	249.82	177.48	91.42	73.07	24.9	1.0000	.05330	279.23
20	250.15	177.57	91.69	73.07	24.9	1.0000	.05313	280.76
20	250.43	177.74	91.88	73.06	24.9	1.0000	.05313	284.42
20	250.85	177.57	91.79	73.07	25.1	1.0000	.05313	289.69
21	250.49	177.31	91.96	73.09	25.1	1.0000	.05313	283.62
21	250.72	177.57	91.66	73.07	25.1	1.0000	.05313	291.99
21	250.37	177.57	91.77	73.07	25.0	1.0000	.05313	289.51
20	250.24	177.48	90.75	73.07	25.0	1.0000	.05313	286.57
20	249.96	177.57	90.96	73.07	24.9	1.0000	.05313	287.68
20	249.77	177.57	90.91	73.06	24.8	1.0000	.05313	290.15
20	250.22	176.89	91.05	73.11	25.2	.3755	.05317	315.34
20	250.17	177.14	91.16	73.09	25.1	.3755	.05317	315.74
20	249.79	177.23	91.34	73.09	24.9	.3755	.05317	314.61
20	250.60	177.40	92.77	73.08	25.1	.5005	.05295	297.90
20	249.64	177.57	91.39	73.06	24.8	.5005	.05295	296.39
20	251.25	177.57	92.13	73.08	25.3	.5005	.05295	299.15
10	290.83	209.96	91.51	71.40	24.7	.3750	.04383	227.38
10	291.20	209.39	91.42	71.44	25.0	.3750	.04383	228.88
10	291.86	209.39	91.73	71.44	25.2	.3750	.04383	234.12
11	290.70	208.81	111.49	71.47	25.1	.3750	.04383	231.28
11	291.58	209.39	112.10	71.44	25.1	.3750	.04383	228.39
11	291.91	209.68	111.72	71.43	25.1	.3750	.04383	228.52
13	290.42	229.80	112.62	70.22	18.0	.3750	.04383	205.40
13	290.16	230.42	112.28	70.18	17.7	.3750	.04383	204.58
13	291.34	230.94	112.59	70.16	17.9	.3750	.04383	208.04
14	291.34	230.73	91.71	70.17	17.9	.3750	.04383	210.11
14	290.78	230.94	91.63	70.15	17.7	.3750	.04383	205.34
14	290.70	231.25	91.40	70.13	17.6	.3750	.04383	207.31
15	291.06	231.25	56.45	70.14	17.7	.3750	.04383	204.42
15	291.08	231.25	56.55	70.14	17.7	.3750	.04383	212.44
15	291.36	231.15	56.51	70.15	17.8	.3750	.04383	209.26
16	291.05	254.52	113.55	68.77	10.4	.3750	.04383	185.50
16	290.56	255.19	113.34	68.72	10.1	.3750	.04383	184.45
16	291.06	254.08	113.53	68.79	10.6	.3750	.04383	185.66
19	251.20	177.31	117.51	73.09	25.3	.3750	.04383	214.37
19	249.30	178.00	116.03	73.03	24.5	.3750	.04383	211.78
19	250.23	177.82	115.86	73.05	24.8	.3750	.04383	212.42
20	249.31	177.14	91.96	73.09	24.8	.3750	.04383	214.31
20	249.94	177.48	91.93	73.07	24.9	.3750	.04383	214.85
20	250.19	177.23	91.39	73.09	25.1	.3750	.04383	214.68
21	250.16	177.06	59.56	73.10	25.1	.3750	.04383	216.68
21	250.05	177.82	59.52	73.05	24.8	.3750	.04383	217.07
21	250.82	177.65	59.61	73.07	25.1	.3750	.04383	212.59
23	250.81	196.69	91.04	71.88	17.9	.3750	.04383	194.38
23	249.74	195.96	90.94	71.92	17.9	.3750	.04383	194.23
23	249.30	196.23	90.89	71.89	17.6	.3750	.04383	192.76
24	249.40	197.80	55.51	71.80	17.1	.3750	.04383	198.85
24	249.78	196.69	55.48	71.87	17.6	.3750	.04383	195.66
24	249.76	197.43	54.31	71.82	17.3	.3750	.04383	187.74
26	250.02	219.27	91.47	70.49	9.8	.3750	.04383	171.89
26	250.51	217.78	91.78	70.58	10.4	.3750	.04383	171.66

26	249.97	218.77	91.88	70.52	10.0	.3750	.04383	169.28
27	249.95	218.87	53.32	70.51	9.9	.3750	.04383	167.25
27	251.12	218.28	54.02	70.56	10.5	.3750	.04383	168.09
27	250.21	218.77	53.43	70.52	10.0	.3750	.04383	167.76
28	210.02	146.50	112.70	74.82	25.0	.3750	.04383	196.94
28	209.38	146.27	112.57	74.83	24.8	.3750	.04383	196.23
28	209.76	146.50	112.61	74.82	24.9	.3750	.04383	196.87
29	211.14	146.57	92.04	74.82	25.3	.3750	.04383	199.90
29	209.89	146.13	91.64	74.85	25.1	.3750	.04383	199.03
29	209.54	146.05	91.52	74.85	25.0	.3750	.04383	198.60
30	210.68	147.38	55.37	74.77	24.8	.3750	.04383	201.17
30	210.73	147.16	55.64	74.78	24.9	.3750	.04383	202.01
30	209.88	146.50	56.11	74.82	24.9	.3750	.04383	200.91
31	209.93	163.67	115.74	73.67	17.5	.3750	.04383	178.74
31	210.03	163.67	115.83	73.67	17.5	.3750	.04383	177.54
31	210.43	163.67	115.95	73.67	17.7	.3750	.04383	178.78
32	210.18	163.11	91.85	73.71	17.8	.3750	.04383	183.42
32	210.38	163.59	91.84	73.68	17.7	.3750	.04383	182.18
32	210.23	163.67	91.87	73.67	17.6	.3750	.04383	182.26
33	208.47	163.84	50.45	73.65	16.9	.3750	.04383	186.92
33	209.45	163.59	50.35	73.67	17.4	.3750	.04383	190.10
33	209.51	163.59	48.20	73.67	17.4	.3750	.04383	184.40
10	291.39	209.29	91.21	71.44	25.1	.5005	.04403	221.09
10	291.47	209.29	91.13	71.44	25.1	.5005	.04403	217.42
10	290.91	209.10	90.98	71.45	25.0	.5005	.04403	219.35
11	290.88	209.68	117.16	71.42	24.8	.5005	.04403	215.23
11	291.16	209.39	117.27	71.44	25.0	.5005	.04403	219.32
11	290.94	209.10	117.51	71.45	25.0	.5005	.04403	217.26
12	290.50	209.68	58.75	71.41	24.7	.5005	.04403	214.33
12	291.35	209.68	58.71	71.42	25.0	.5005	.04403	217.25
12	290.87	208.91	59.42	71.46	25.1	.5005	.04403	215.37
13	290.62	231.77	109.65	70.10	17.4	.5005	.04403	197.58
13	290.70	231.46	109.84	70.12	17.5	.5005	.04403	189.16
13	290.98	231.35	109.62	70.13	17.6	.5005	.04403	193.76
14	291.62	230.63	92.11	70.18	18.0	.5005	.04403	196.38
14	290.91	230.53	91.68	70.18	17.9	.5005	.04403	193.25
14	290.77	229.60	92.06	70.23	18.1	.5005	.04403	195.80
15	291.59	232.60	56.98	70.06	17.4	.5005	.04403	194.46
15	291.65	231.56	58.07	70.12	17.7	.5005	.04403	203.80
15	291.49	231.77	57.76	70.11	17.6	.5005	.04403	202.80
16	290.12	255.08	115.45	68.73	10.0	.5005	.04403	170.91
16	288.92	255.63	115.20	68.68	9.5	.5005	.04403	166.59
19	250.79	177.57	116.58	73.07	25.1	.5005	.04403	204.29
19	250.55	177.40	116.59	73.08	25.1	.5005	.04403	205.24
19	250.75	177.23	116.51	73.09	25.2	.5005	.04403	205.43
20	250.37	177.57	90.63	73.07	25.0	.5005	.04403	208.89
20	251.03	177.06	90.77	73.11	25.4	.5005	.04403	207.47
20	250.02	176.97	90.81	73.10	25.1	.5005	.04403	200.90
21	250.28	176.63	58.11	73.13	25.3	.5005	.04403	209.53
21	249.88	177.31	57.75	73.08	24.9	.5005	.04403	200.37
21	249.39	177.06	57.28	73.09	24.9	.5005	.04403	208.15
22	249.56	197.33	110.95	71.83	17.3	.5005	.04403	184.60
22	249.57	195.86	111.18	71.92	17.8	.5005	.04403	182.14
22	249.27	196.41	111.00	71.88	17.5	.5005	.04403	181.19
23	251.21	197.15	91.87	71.85	17.9	.5005	.04403	181.32
23	249.56	197.80	91.22	71.80	17.1	.5005	.04403	179.99
23	250.34	198.07	91.48	71.79	17.3	.5005	.04403	186.96
24	249.85	196.14	58.99	71.90	17.8	.5005	.04403	185.57
24	249.93	197.80	58.50	71.80	17.3	.5005	.04403	186.64
28	210.99	146.50	112.57	74.83	25.3	.5005	.04403	190.13
28	210.66	146.50	112.48	74.83	25.2	.5005	.04403	189.49
28	210.92	146.72	112.46	74.81	25.2	.5005	.04403	189.16
29	209.85	145.76	91.53	74.87	25.2	.5005	.04403	190.24
29	210.53	146.05	91.55	74.86	25.3	.5005	.04403	191.05
29	210.08	146.27	91.60	74.84	25.1	.5005	.04403	189.60
30	211.46	146.72	63.20	74.82	25.4	.5005	.04403	192.10
30	210.84	146.50	63.45	74.83	25.2	.5005	.04403	191.61

30	210.87	146.72	63.28	74.81	25.1	.5005	.04403	190.92
31	209.98	163.43	109.97	73.69	17.6	.5005	.04403	167.04
31	210.03	163.35	109.90	73.69	17.7	.5005	.04403	164.47
31	210.13	163.75	109.97	73.67	17.5	.5005	.04403	170.28
32	210.31	163.67	90.58	73.67	17.6	.5005	.04403	167.34
32	210.38	163.92	90.62	73.66	17.5	.5005	.04403	169.39
32	208.93	163.27	91.55	73.69	17.3	.5005	.04403	166.44
33	209.68	164.00	59.52	73.65	17.3	.5005	.04403	169.53
33	209.95	163.92	59.66	73.66	17.4	.5005	.04403	167.41
33	210.20	163.27	60.14	73.70	17.8	.5005	.04403	179.88
10	292.10	209.68	91.51	71.43	25.1	.3755	.05317	325.05
10	292.16	209.68	91.57	71.43	25.2	.3755	.05317	331.65
10	291.61	210.16	91.28	71.39	24.9	.3755	.05317	331.52
11	292.65	210.83	114.15	71.36	24.9	.3755	.05317	326.43
11	292.61	210.54	114.28	71.38	25.0	.3755	.05317	327.65
11	290.40	208.91	113.85	71.46	25.0	.3755	.05317	329.13
12	289.86	207.47	68.47	71.54	25.3	.3755	.05317	340.51
12	290.36	207.95	68.47	71.52	25.3	.3755	.05317	334.44
12	290.31	208.33	68.39	71.49	25.1	.3755	.05317	330.09
13	290.34	230.63	115.81	70.17	17.7	.3755	.05317	302.07
13	290.53	231.25	115.72	70.13	17.5	.3755	.05317	303.53
13	291.02	230.63	116.05	70.17	17.9	.3755	.05317	294.43
14	290.60	232.29	90.80	70.07	17.2	.3755	.05317	311.76
14	290.89	231.98	90.77	70.09	17.4	.3755	.05317	303.05
14	291.19	231.66	91.09	70.11	17.6	.3755	.05317	315.84
15	290.91	230.63	65.61	70.17	17.8	.3755	.05317	311.31
15	291.13	230.73	65.70	70.17	17.9	.3755	.05317	316.66
15	290.50	231.77	65.65	70.10	17.4	.3755	.05317	314.17
16	290.60	255.63	111.10	68.70	10.0	.3755	.05317	288.22
16	290.53	255.08	110.95	68.73	10.1	.3755	.05317	282.26
16	290.56	254.74	111.08	68.75	10.2	.3755	.05317	286.39
19	249.28	176.80	111.86	73.11	25.0	.3755	.05317	311.87
19	250.36	176.46	112.09	73.14	25.4	.3755	.05317	313.01
20	249.79	177.74	91.61	73.05	24.7	.3755	.05317	313.44
20	249.84	178.00	91.55	73.04	24.6	.3755	.05317	314.02
20	250.49	177.65	91.94	73.06	25.0	.3755	.05317	316.52
21	250.75	178.59	64.84	73.01	24.7	.3755	.05317	317.23
21	250.34	177.74	65.09	73.06	24.9	.3755	.05317	314.32
21	250.65	177.91	65.07	73.05	24.9	.3755	.05317	319.80
22	249.19	196.97	117.99	71.85	17.3	.3755	.05317	297.10
22	249.41	196.69	118.17	71.87	17.5	.3755	.05317	294.55
22	249.21	196.69	118.25	71.87	17.4	.3755	.05317	294.02
23	250.24	196.69	91.90	71.87	17.7	.3755	.05317	295.93
23	249.69	196.78	91.81	71.86	17.5	.3755	.05317	300.27
23	250.64	196.97	92.06	71.86	17.8	.3755	.05317	309.33
28	209.92	146.50	114.98	74.82	24.9	.3755	.05317	282.48
28	210.60	146.50	115.01	74.83	25.1	.3755	.05317	283.91
28	210.51	146.50	115.21	74.83	25.1	.3755	.05317	283.91
29	209.75	147.09	90.85	74.78	24.6	.3755	.05317	291.67
29	210.16	146.94	90.94	74.79	24.8	.3755	.05317	292.19
29	209.89	146.57	90.76	74.82	24.9	.3755	.05317	292.67
30	211.01	146.27	57.45	74.84	25.4	.3755	.05317	299.31
30	210.19	146.50	57.41	74.82	25.0	.3755	.05317	298.67
30	210.09	146.79	57.40	74.80	24.8	.3755	.05317	298.37
31	208.13	163.51	110.83	73.67	16.9	.3755	.05317	267.84
31	212.05	163.27	111.32	73.71	18.4	.3755	.05317	272.24
31	209.41	162.87	111.44	73.72	17.6	.3755	.05317	272.37
32	210.91	165.04	90.84	73.59	17.3	.3755	.05317	276.43
32	212.13	164.64	91.26	73.62	17.9	.3755	.05317	277.54
32	210.04	164.64	90.72	73.61	17.1	.3755	.05317	279.26
33	210.76	163.84	57.24	73.67	17.7	.3755	.05317	282.66
33	210.28	163.59	57.42	73.68	17.6	.3755	.05317	286.88
33	210.40	164.08	57.33	73.65	17.5	.3755	.05317	278.88
10	292.27	209.87	90.94	71.42	25.1	.5005	.05295	317.75
10	291.88	209.68	90.93	71.42	25.1	.5005	.05295	316.73
10	292.44	209.87	90.93	71.42	25.2	.5005	.05295	317.63
11	292.64	233.02	91.48	70.05	17.5	.5005	.05295	284.45

11	291.15	231.15	91.40	70.14	17.7	.5005	.05295	284.26
11	291.62	231.66	91.32	70.12	17.7	.5005	.05295	282.76
12	290.43	255.30	91.22	68.72	10.0	.5005	.05295	247.61
12	291.76	256.08	91.61	68.68	10.2	.5005	.05295	248.47
12	291.72	256.30	91.45	68.67	10.1	.5005	.05295	253.18
13	290.34	254.30	110.19	68.77	10.3	.5005	.05295	249.25
13	291.45	255.75	109.62	68.70	10.2	.5005	.05295	249.93
13	291.38	256.08	109.81	68.68	10.1	.5005	.05295	249.37
14	289.89	254.41	77.17	68.76	10.1	.5005	.05295	264.06
14	291.35	255.52	76.99	68.71	10.2	.5005	.05295	251.39
14	290.92	255.30	77.14	68.72	10.2	.5005	.05295	257.76
15	249.17	175.87	91.72	73.17	25.3	.5005	.05295	296.52
15	249.55	176.97	91.54	73.10	25.0	.5005	.05295	295.45
15	249.28	176.80	91.58	73.11	25.0	.5005	.05295	295.33
16	249.24	196.14	90.72	71.90	17.6	.5005	.05295	267.67
16	249.55	196.41	90.61	71.89	17.6	.5005	.05295	267.94
16	248.96	196.41	91.82	71.88	17.5	.5005	.05295	267.00
17	249.74	218.08	91.37	70.56	10.1	.5005	.05295	244.72
17	249.96	218.18	91.25	70.56	10.2	.5005	.05295	240.83
17	250.07	218.58	91.41	70.53	10.1	.5005	.05295	236.74
18	250.54	218.97	113.62	70.51	10.1	.5005	.05295	243.54
18	250.50	219.37	113.70	70.49	9.9	.5005	.05295	234.87
18	250.17	218.97	113.85	70.51	9.9	.5005	.05295	234.72
19	251.30	219.77	73.36	70.47	10.0	.5005	.05295	243.03
19	250.38	219.17	73.57	70.50	9.9	.5005	.05295	241.45
19	250.53	218.68	74.50	70.53	10.2	.5005	.05295	239.24
20	209.64	145.83	91.09	74.87	25.1	.5005	.05295	275.34
20	209.65	145.83	91.69	74.87	25.1	.5005	.05295	274.16
20	209.54	146.13	91.51	74.84	25.0	.5005	.05295	273.84
21	209.54	163.19	91.83	73.70	17.5	.5005	.05295	249.01
21	209.90	163.59	91.93	73.68	17.5	.5005	.05295	249.77
21	209.56	163.51	91.58	73.68	17.4	.5005	.05295	248.40
22	210.70	183.00	91.09	72.42	10.1	.5005	.05295	228.77
22	210.50	183.08	91.19	72.42	9.9	.5005	.05295	226.06
22	210.55	183.08	91.29	72.42	10.0	.5005	.05295	219.57
23	210.37	183.00	113.30	72.42	9.9	.5005	.05295	220.82
23	210.17	182.13	113.53	72.47	10.2	.5005	.05295	214.93
23	209.82	182.74	113.68	72.43	9.9	.5005	.05295	223.10
24	210.08	182.13	72.50	72.47	10.2	.5005	.05295	232.46
24	209.56	182.39	72.49	72.45	9.9	.5005	.05295	229.33
24	209.91	182.74	72.45	72.43	9.9	.5005	.05295	222.86
25	210.46	182.65	49.59	72.44	10.1	.5005	.05295	228.74
25	211.24	183.70	50.00	72.38	10.0	.5005	.05295	235.30
26	210.52	146.27	55.86	74.84	25.2	.5005	.05295	279.16
26	210.15	146.57	55.68	74.82	25.0	.5005	.05295	277.59
26	210.33	146.94	55.45	74.79	24.9	.5005	.05295	277.72
27	210.28	146.50	111.90	74.82	25.0	.5005	.05295	274.28
27	210.11	146.50	111.65	74.82	25.0	.5005	.05295	274.80
27	210.53	146.13	112.02	74.85	25.3	.5005	.05295	276.06
28	250.48	177.74	113.08	73.06	25.0	.5005	.05295	296.38
28	250.73	177.82	113.24	73.06	25.0	.5005	.05295	297.24
28	251.14	177.31	112.96	73.09	25.3	.5005	.05295	298.93
29	250.04	177.31	62.04	73.08	25.0	.5005	.05295	299.21
29	249.62	177.14	62.43	73.09	24.9	.5005	.05295	296.82
29	250.32	177.06	62.43	73.10	25.2	.5005	.05295	300.22
30	290.38	208.23	67.39	71.50	25.2	.5005	.05295	320.47
30	290.05	207.95	67.73	71.51	25.2	.5005	.05295	322.28
30	289.57	207.95	67.88	71.51	25.1	.5005	.05295	318.83
31	291.14	209.00	108.27	71.46	25.1	.5005	.05295	317.37
31	291.45	209.68	107.94	71.42	25.0	.5005	.05295	317.13
31	291.90	209.48	108.07	71.44	25.2	.5005	.05295	318.45
32	290.38	230.84	111.19	70.16	17.6	.5005	.05295	283.94
32	290.49	230.84	111.02	70.16	17.6	.5005	.05295	282.48
32	291.04	231.04	110.56	70.15	17.7	.5005	.05295	285.27
33	291.42	231.56	63.14	70.12	17.7	.5005	.05295	284.18
33	291.38	231.77	62.95	70.11	17.6	.5005	.05295	295.90
33	291.40	231.98	62.98	70.10	17.5	.5005	.05295	286.73

34	250.24	196.97	57.79	71.86	17.6	.5005	.05295	268.81
34	250.07	196.97	57.67	71.86	17.6	.5005	.05295	269.96
34	249.93	197.15	57.86	71.84	17.5	.5005	.05295	271.22
35	250.05	197.24	107.28	71.84	17.5	.5005	.05295	267.87
35	250.03	197.15	107.28	71.84	17.5	.5005	.05295	267.67
35	250.11	196.69	107.11	71.87	17.7	.5005	.05295	268.63
36	211.12	164.08	115.84	73.65	17.7	.5005	.05295	249.26
36	210.04	163.67	116.10	73.67	17.5	.5005	.05295	248.49
36	209.61	163.43	116.01	73.68	17.5	.5005	.05295	248.50
37	209.74	162.87	52.66	73.72	17.8	.5005	.05295	254.54
37	209.84	163.51	52.65	73.68	17.5	.5005	.05295	253.94
37	209.83	163.75	52.62	73.67	17.4	.5005	.05295	252.67
38	249.02	196.23	58.16	71.89	17.5	.5005	.05295	265.25
38	249.19	196.05	58.22	71.91	17.6	.5005	.05295	274.00
38	249.33	196.60	58.28	71.87	17.5	.5005	.05295	269.74
11	289.93	207.76	112.16	71.52	25.2	.5005	.05295	317.37
11	289.76	207.95	112.18	71.51	25.1	.5005	.05295	316.97
11	290.43	208.33	112.33	71.49	25.2	.5005	.05295	317.78
15	291.70	232.18	65.47	70.09	17.5	.5005	.05295	286.88
15	290.21	230.11	66.48	70.20	17.8	.5005	.05295	287.85
15	290.43	230.53	66.48	70.18	17.7	.5005	.05295	287.40
18	289.37	253.86	60.82	68.79	10.2	.5005	.05295	255.81
18	289.29	254.86	61.08	68.73	9.9	.5005	.05295	249.35
18	289.82	255.97	61.49	68.67	9.7	.5005	.05295	255.27
24	249.11	195.32	61.70	71.95	17.9	.5005	.05295	271.23
24	248.87	195.59	61.76	71.93	17.7	.5005	.05295	274.59
24	249.47	196.23	61.95	71.90	17.7	.5005	.05295	275.07
25	251.61	218.28	116.05	70.56	10.6	.5005	.05295	245.39
25	249.45	218.28	115.78	70.54	10.0	.5005	.05295	237.41
25	249.68	218.77	115.36	70.52	9.9	.5005	.05295	231.77
26	250.72	219.67	91.49	70.47	9.9	.5005	.05295	235.23
26	250.39	219.07	91.54	70.50	10.0	.5005	.05295	239.22
26	250.64	218.18	91.93	70.56	10.4	.5005	.05295	241.49
27	251.73	218.97	56.34	70.52	10.4	.5005	.05295	243.70
27	251.04	219.27	56.22	70.50	10.1	.5005	.05295	242.29
27	249.30	218.68	56.05	70.52	9.8	.5005	.05295	240.97
34	209.26	182.13	118.77	72.47	9.9	.5005	.05295	218.20
34	210.21	182.47	120.29	72.45	10.1	.5005	.05295	220.71
34	209.57	182.21	120.05	72.46	10.0	.5005	.05295	222.40
35	209.26	182.04	91.38	72.47	9.9	.5005	.05295	226.37
35	209.61	181.69	91.21	72.50	10.2	.5005	.05295	234.80
35	209.57	182.65	91.67	72.44	9.8	.5005	.05295	232.90
36	209.91	183.26	50.96	72.40	9.7	.5005	.05295	222.28
36	209.71	183.00	51.02	72.42	9.7	.5005	.05295	226.32
36	209.31	182.65	51.36	72.43	9.7	.5005	.05295	222.99
14	290.22	231.56	91.24	70.11	17.3	.3755	.05317	315.92
14	289.80	231.56	91.49	70.11	17.2	.3755	.05317	317.13
14	290.34	231.56	91.22	70.11	17.4	.3755	.05317	316.12
15	290.93	231.15	71.06	70.14	17.7	.3755	.05317	319.07
15	290.60	229.91	72.02	70.21	18.0	.3755	.05317	320.21
15	291.32	231.56	71.87	70.12	17.6	.3755	.05317	320.42
23	250.52	196.69	91.27	71.88	17.8	.3755	.05317	305.29
23	251.02	197.70	91.10	71.82	17.6	.3755	.05317	303.86
23	250.14	197.80	91.09	71.80	17.3	.3755	.05317	303.17
33	209.25	164.08	55.38	73.64	17.1	.3755	.05317	284.95
33	209.84	163.11	55.71	73.71	17.7	.3755	.05317	286.06
33	209.43	163.67	55.52	73.67	17.3	.3755	.05317	285.14
10	290.74	208.62	103.16	71.48	25.1	.4995	.06775	575.02
10	290.61	209.00	103.03	71.45	25.0	.4995	.06775	572.45
10	290.63	209.29	102.70	71.44	24.9	.4995	.06775	572.48
11	290.45	230.73	94.52	70.16	17.7	.4995	.06775	514.18
11	290.21	230.42	94.52	70.18	17.7	.4995	.06775	514.95
11	291.00	231.46	95.03	70.13	17.6	.4995	.06775	512.78
12	291.12	254.97	91.37	68.74	10.3	.4995	.06775	469.75
12	290.46	254.86	91.26	68.74	10.2	.4995	.06775	467.99
12	289.97	255.19	91.00	68.72	9.9	.4995	.06775	465.63
13	290.95	256.19	105.44	68.67	9.9	.4995	.06775	453.67

13	291.27	255.86	105.71	68.69	10.1	.4995	.06775	457.10
13	291.13	255.86	105.58	68.69	10.1	.4995	.06775	458.66
14	290.29	255.41	86.95	68.71	10.0	.4995	.06775	468.92
14	290.31	254.97	86.97	68.73	10.1	.4995	.06775	463.34
14	290.01	254.52	87.09	68.76	10.1	.4995	.06775	461.23
17	251.51	219.67	91.42	70.48	10.1	.4995	.06775	431.73
17	251.52	219.37	91.60	70.50	10.2	.4995	.06775	424.25
17	251.17	219.77	91.55	70.47	10.0	.4995	.06775	426.96
18	250.11	218.77	109.81	70.52	10.0	.4995	.06775	426.45
18	249.18	217.88	109.72	70.57	10.0	.4995	.06775	424.92
18	250.79	218.68	109.31	70.53	10.2	.4995	.06775	426.64
19	249.70	217.88	79.39	70.57	10.2	.4995	.06775	426.48
19	249.66	217.88	79.43	70.57	10.2	.4995	.06775	435.72
19	249.57	218.18	79.34	70.55	10.0	.4995	.06775	429.47
20	210.89	146.64	90.85	74.82	25.2	.4995	.06775	507.85
20	210.83	146.87	90.85	74.80	25.1	.4995	.06775	506.73
20	210.71	146.94	91.11	74.80	25.0	.4995	.06775	506.14
21	211.22	165.04	90.75	73.59	17.4	.4995	.06775	450.79
21	210.94	164.64	90.97	73.61	17.4	.4995	.06775	451.26
21	211.19	164.80	91.16	73.61	17.5	.4995	.06775	452.38
22	210.37	182.56	91.18	72.45	10.1	.4995	.06775	405.75
22	210.69	182.82	91.09	72.43	10.1	.4995	.06775	404.04
22	210.46	182.74	91.10	72.44	10.1	.4995	.06775	397.03
23	210.68	183.52	106.41	72.39	9.9	.4995	.06775	397.13
23	210.62	183.61	105.98	72.38	9.8	.4995	.06775	399.55
23	210.77	182.82	106.35	72.43	10.1	.4995	.06775	397.86
24	210.91	183.43	70.75	72.40	10.0	.4995	.06775	401.27
24	210.37	183.00	70.93	72.42	9.9	.4995	.06775	403.36
24	210.60	183.08	70.91	72.42	10.0	.4995	.06775	402.48
25	275.37	240.92	84.97	69.42	10.3	.4995	.06775	443.81
25	275.32	241.34	84.89	69.39	10.1	.4995	.06775	442.39
25	275.32	241.88	84.69	69.36	9.9	.4995	.06775	442.15
26	275.69	241.88	109.76	69.37	10.0	.4995	.06775	437.56
26	275.83	241.56	109.78	69.39	10.2	.4995	.06775	444.57
26	275.28	241.45	110.13	69.39	10.1	.4995	.06775	443.74
27	292.01	256.30	107.84	68.67	10.2	.4995	.06775	456.36
27	291.44	256.19	108.14	68.67	10.0	.4995	.06775	455.42
27	291.69	256.42	108.03	68.66	10.0	.4995	.06775	455.46
28	290.82	255.97	87.13	68.68	9.9	.4995	.06775	455.22
28	290.73	255.41	87.76	68.71	10.1	.4995	.06775	450.89
28	291.54	255.86	87.64	68.69	10.2	.4995	.06775	459.61
11	294.17	208.52	119.05	71.51	26.1	.3760	.06797	560.85
11	290.13	208.52	119.98	71.48	25.0	.3760	.06797	554.73
11	292.25	208.81	119.58	71.48	25.5	.3760	.06797	557.89
13	292.12	231.35	117.90	70.14	17.9	.3760	.06797	521.69
13	292.92	232.18	117.41	70.10	17.9	.3760	.06797	520.59
13	291.50	232.18	117.25	70.09	17.5	.3760	.06797	519.85
16	293.14	256.42	112.19	68.68	10.4	.3760	.06797	494.88
16	291.79	257.31	111.69	68.61	9.8	.3760	.06797	493.25
16	292.95	256.53	112.02	68.67	10.4	.3760	.06797	493.25
19	250.46	176.80	113.45	73.12	25.3	.3760	.06797	524.42
19	250.99	176.80	113.13	73.12	25.5	.3760	.06797	524.46
19	251.16	178.34	113.23	73.03	24.9	.3760	.06797	522.72
20	249.41	177.65	91.77	73.06	24.6	.3760	.06797	530.41
20	249.00	177.31	91.84	73.07	24.7	.3760	.06797	531.12
20	250.05	177.31	91.45	73.08	25.0	.3760	.06797	530.37
22	249.96	197.33	114.19	71.83	17.4	.3760	.06797	500.04
22	250.86	196.51	114.53	71.89	18.0	.3760	.06797	503.05
22	251.50	196.97	114.43	71.87	18.0	.3760	.06797	503.55
25	249.96	218.77	113.50	70.52	10.0	.3760	.06797	479.83
25	249.11	218.58	113.35	70.52	9.8	.3760	.06797	468.86
25	250.30	218.68	113.31	70.53	10.1	.3760	.06797	473.62
28	208.70	146.05	112.74	74.84	24.7	.3760	.06797	469.38
28	209.43	146.50	113.51	74.82	24.8	.3760	.06797	470.18
28	209.49	146.27	113.08	74.83	24.9	.3760	.06797	470.25
29	211.16	146.64	91.12	74.82	25.3	.3760	.06797	491.79
29	209.77	146.87	90.72	74.80	24.7	.3760	.06797	488.78

29	210.93	146.87	90.78	74.80	25.1	.3760	.06797	490.48
31	209.95	163.11	112.19	73.71	17.7	.3760	.06797	453.08
31	210.10	162.95	112.20	73.72	17.9	.3760	.06797	454.30
31	210.16	163.03	112.11	73.72	17.8	.3760	.06797	453.87
32	210.26	164.08	91.88	73.65	17.4	.3760	.06797	470.46
32	210.52	163.67	91.82	73.68	17.7	.3760	.06797	471.66
32	210.08	163.84	92.12	73.66	17.5	.3760	.06797	470.68
34	208.94	183.00	110.51	72.41	9.4	.3760	.06797	434.61
34	209.87	182.13	110.75	72.47	10.1	.3760	.06797	439.17
34	209.40	182.39	110.70	72.45	9.8	.3760	.06797	433.41
37	290.48	209.00	95.23	71.45	25.0	.3760	.06797	557.19
37	291.67	209.39	95.17	71.44	25.1	.3760	.06797	559.11
37	290.81	209.96	95.01	71.40	24.7	.3760	.06797	557.19
38	291.54	231.04	95.74	70.15	17.9	.3760	.06797	529.91
38	291.39	231.04	96.24	70.15	17.8	.3760	.06797	529.12
38	290.57	231.56	96.22	70.12	17.4	.3760	.06797	527.33
39	291.66	255.63	92.49	68.71	10.3	.3760	.06797	492.97
39	290.27	256.53	92.66	68.64	9.6	.3760	.06797	500.20
39	291.56	256.19	92.52	68.67	10.1	.3760	.06797	490.06
40	249.73	197.52	87.85	71.82	17.3	.3760	.06797	508.20
40	249.53	196.87	87.85	71.86	17.5	.3760	.06797	510.57
40	249.56	197.06	88.10	71.85	17.4	.3760	.06797	515.41
41	249.76	218.18	82.46	70.55	10.1	.3760	.06797	490.76
41	249.78	217.88	82.56	70.57	10.2	.3760	.06797	485.95
41	249.74	218.87	82.68	70.51	9.9	.3760	.06797	486.01
42	210.52	146.79	79.14	74.81	25.0	.3760	.06797	496.80
42	210.62	146.72	79.20	74.81	25.1	.3760	.06797	496.12
42	210.78	146.64	79.21	74.82	25.1	.3760	.06797	496.59
43	209.25	163.84	77.00	73.66	17.2	.3760	.06797	475.01
43	209.61	163.59	76.77	73.67	17.4	.3760	.06797	475.39
43	210.01	163.59	77.02	73.68	17.5	.3760	.06797	477.78
44	210.11	181.69	75.70	72.50	10.4	.3760	.06797	459.13
44	209.87	183.43	75.78	72.39	9.6	.3760	.06797	460.51
20	249.31	177.23	90.08	73.08	24.8	.5000	.06792	502.44
20	250.57	176.55	89.94	73.13	25.4	.5000	.06792	501.92
20	249.69	176.72	90.01	73.12	25.1	.5000	.06792	500.41

APPENDIX B. EXPERIMENTAL DATA FOR THE CHAMFERED SHORT TUBES

TEST	PUP PSIA	PSAT PSIA	PDOWN PSIA	RHO LB/FT3	SUBCOOLING F	LENGTH INCH	DIAMETER INCH	M LB/H	DEPTH INCH
11	290.83	209.68	119.32	71.42	24.8	.3750	.06787	613.86	.0134
11	291.26	209.39	119.17	71.44	25.0	.3750	.06787	616.44	.0134
11	290.31	208.81	119.10	71.46	25.0	.3750	.06787	614.29	.0134
13	290.10	232.50	118.75	70.06	17.0	.3750	.06787	554.93	.0134
13	290.94	231.56	118.83	70.12	17.5	.3750	.06787	559.32	.0134
13	290.59	232.08	118.95	70.08	17.3	.3750	.06787	556.76	.0134
16	291.84	258.09	123.49	68.56	9.6	.3750	.06787	521.85	.0134
16	292.53	257.42	123.31	68.61	10.0	.3750	.06787	527.97	.0134
16	292.28	257.09	123.46	68.63	10.0	.3750	.06787	516.94	.0134
19	249.53	176.21	120.24	73.15	25.3	.3750	.06787	582.59	.0134
19	249.73	176.72	120.25	73.12	25.1	.3750	.06787	582.92	.0134
19	249.38	175.96	119.65	73.16	25.3	.3750	.06787	583.66	.0134
22	249.93	196.97	118.46	71.85	17.5	.3750	.06787	531.39	.0134
22	249.93	197.24	118.69	71.84	17.5	.3750	.06787	531.84	.0134
22	249.76	197.24	118.70	71.84	17.4	.3750	.06787	530.61	.0134
25	250.19	219.07	114.81	70.50	9.9	.3750	.06787	495.79	.0134
25	250.16	218.77	115.04	70.52	10.0	.3750	.06787	495.33	.0134
25	250.50	218.77	114.69	70.52	10.1	.3750	.06787	500.49	.0134
26	250.47	218.87	91.65	70.52	10.1	.3750	.06787	497.24	.0134
26	250.85	218.77	91.51	70.53	10.2	.3750	.06787	498.81	.0134
26	250.86	218.97	91.56	70.51	10.2	.3750	.06787	502.63	.0134
28	210.81	147.53	119.07	74.76	24.8	.3750	.06787	541.22	.0134
28	211.87	147.31	119.21	74.78	25.2	.3750	.06787	544.38	.0134
28	210.91	147.09	119.08	74.79	25.0	.3750	.06787	541.93	.0134
31	210.13	162.63	115.47	73.74	18.0	.3750	.06787	501.11	.0134
31	210.98	163.11	115.78	73.72	18.1	.3750	.06787	502.46	.0134
31	210.01	163.67	115.20	73.67	17.5	.3750	.06787	498.41	.0134
32	210.18	163.11	91.71	73.71	17.8	.3750	.06787	506.81	.0134
32	209.79	163.67	91.34	73.67	17.4	.3750	.06787	505.26	.0134
32	210.50	162.71	91.36	73.74	18.1	.3750	.06787	507.88	.0134
34	211.31	182.30	118.37	72.47	10.5	.3750	.06787	466.97	.0134
34	209.77	182.74	118.38	72.43	9.8	.3750	.06787	462.65	.0134
34	210.81	181.87	118.74	72.50	10.5	.3750	.06787	465.73	.0134
35	210.71	182.74	90.58	72.44	10.2	.3750	.06787	484.12	.0134
35	209.85	182.21	90.95	72.47	10.1	.3750	.06787	470.77	.0134
35	209.74	182.65	90.74	72.44	9.9	.3750	.06787	467.54	.0134
37	292.08	209.68	108.19	71.43	25.1	.3750	.06787	620.10	.0134
37	291.69	210.06	107.76	71.40	24.9	.3750	.06787	616.39	.0134
37	291.18	208.23	108.10	71.51	25.4	.3750	.06787	621.71	.0134
38	292.60	231.35	100.16	70.15	18.0	.3750	.06787	569.35	.0134
38	291.36	231.35	99.87	70.13	17.7	.3750	.06787	562.24	.0134
38	292.26	231.66	100.32	70.12	17.9	.3750	.06787	569.39	.0134
40	251.01	176.46	95.65	73.14	25.6	.3750	.06787	592.31	.0134
40	249.87	176.80	95.59	73.11	25.1	.3750	.06787	588.05	.0134
40	249.90	176.55	95.40	73.13	25.2	.3750	.06787	589.32	.0134
41	249.49	196.97	93.66	71.85	17.4	.3750	.06787	535.28	.0134
41	249.35	197.06	93.82	71.84	17.3	.3750	.06787	538.23	.0134
41	249.53	197.24	93.57	71.83	17.3	.3750	.06787	535.61	.0134
42	209.89	147.16	86.26	74.78	24.6	.3750	.06787	545.12	.0134
42	210.05	146.50	86.45	74.82	25.0	.3750	.06787	549.04	.0134
42	210.56	146.20	87.19	74.85	25.3	.3750	.06787	550.23	.0134
43	210.33	181.69	79.45	72.50	10.4	.3750	.06787	479.35	.0134
43	210.45	182.47	79.45	72.45	10.2	.3750	.06787	480.66	.0134
43	210.56	182.91	79.32	72.43	10.0	.3750	.06787	475.51	.0134
11	290.51	208.81	123.36	71.47	25.0	.3770	.06777	606.89	.0112

11	291.30	209.39	123.52	71.44	25.0	.3770	.06777	606.89	.0112
11	289.72	207.66	123.54	71.53	25.2	.3770	.06777	607.47	.0112
13	291.46	231.87	121.36	70.10	17.6	.3770	.06777	554.02	.0112
13	290.86	231.56	121.89	70.12	17.5	.3770	.06777	552.98	.0112
13	290.90	231.25	122.01	70.14	17.6	.3770	.06777	553.21	.0112
16	290.20	255.63	113.06	68.69	9.9	.3770	.06777	513.67	.0112
16	290.79	254.97	113.10	68.74	10.2	.3770	.06777	516.40	.0112
16	290.35	254.86	113.06	68.74	10.1	.3770	.06777	516.18	.0112
19	250.28	178.00	124.98	73.04	24.8	.3770	.06777	576.93	.0112
19	250.08	177.48	124.99	73.07	24.9	.3770	.06777	577.90	.0112
19	250.68	177.06	124.99	73.10	25.3	.3770	.06777	580.43	.0112
22	250.10	197.33	120.45	71.83	17.5	.3770	.06777	533.76	.0112
22	248.54	197.15	119.36	71.83	17.1	.3770	.06777	530.34	.0112
22	248.83	196.60	119.26	71.87	17.3	.3770	.06777	531.91	.0112
25	251.21	218.77	114.41	70.53	10.3	.3770	.06777	502.33	.0112
25	250.56	218.87	114.29	70.52	10.1	.3770	.06777	507.11	.0112
25	250.02	218.87	113.98	70.51	9.9	.3770	.06777	502.09	.0112
28	210.77	146.05	115.36	74.86	25.4	.3770	.06777	538.77	.0112
28	209.72	146.35	115.01	74.83	24.9	.3770	.06777	536.00	.0112
28	209.58	146.05	114.82	74.85	25.0	.3770	.06777	536.21	.0112
29	210.22	145.76	91.55	74.87	25.4	.3770	.06777	547.96	.0112
29	209.91	146.05	91.45	74.85	25.1	.3770	.06777	546.91	.0112
29	210.30	146.20	91.50	74.84	25.2	.3770	.06777	547.62	.0112
31	210.43	164.56	111.27	73.62	17.3	.3770	.06777	504.85	.0112
31	210.61	164.48	111.31	73.62	17.4	.3770	.06777	505.83	.0112
31	211.16	163.84	111.94	73.67	17.9	.3770	.06777	509.14	.0112
32	209.97	163.59	90.54	73.68	17.5	.3770	.06777	515.63	.0112
32	210.26	163.59	90.74	73.68	17.6	.3770	.06777	514.04	.0112
32	210.06	163.67	90.73	73.67	17.5	.3770	.06777	513.26	.0112
35	209.79	182.47	92.12	72.45	9.9	.3770	.06777	481.17	.0112
35	209.58	182.47	91.62	72.45	9.9	.3770	.06777	479.20	.0112
35	209.49	181.87	91.68	72.49	10.1	.3770	.06777	479.03	.0112
37	290.41	208.23	105.86	71.50	25.2	.3770	.06777	608.52	.0112
37	290.20	207.66	106.00	71.53	25.3	.3770	.06777	608.79	.0112
37	290.45	209.39	105.53	71.43	24.8	.3770	.06777	604.86	.0112
39	289.79	255.30	94.32	68.71	9.9	.3770	.06777	511.88	.0112
39	289.92	254.52	94.38	68.76	10.1	.3770	.06777	513.76	.0112
39	288.47	253.41	94.66	68.81	10.1	.3770	.06777	513.38	.0112
40	249.46	177.23	94.50	73.08	24.8	.3770	.06777	581.81	.0112
40	249.45	176.97	94.51	73.10	24.9	.3770	.06777	582.02	.0112
40	249.32	176.89	94.51	73.10	24.9	.3770	.06777	581.68	.0112
41	249.75	197.43	92.41	71.82	17.3	.3770	.06777	541.90	.0112
41	249.93	196.97	92.48	71.85	17.5	.3770	.06777	539.16	.0112
41	250.03	196.87	92.57	71.86	17.6	.3770	.06777	541.16	.0112
43	210.53	146.05	85.87	74.86	25.3	.3770	.06777	549.11	.0112
43	210.32	146.35	85.75	74.83	25.1	.3770	.06777	548.72	.0112
43	210.32	146.35	85.86	74.83	25.1	.3770	.06777	548.57	.0112
44	208.96	163.51	81.38	73.67	17.2	.3770	.06777	512.62	.0112
44	209.87	164.16	81.11	73.64	17.3	.3770	.06777	515.93	.0112
44	209.77	163.92	81.02	73.65	17.3	.3770	.06777	516.33	.0112
45	210.89	182.39	78.56	72.46	10.4	.3770	.06777	485.44	.0112
45	210.61	182.13	78.66	72.48	10.4	.3770	.06777	488.52	.0112
45	210.24	182.04	78.59	72.48	10.3	.3770	.06777	483.62	.0112
11	290.54	209.10	116.76	71.45	24.9	.5005	.06765	529.73	.0081
11	291.04	208.33	117.44	71.50	25.3	.5005	.06765	532.82	.0081
11	290.64	208.81	117.31	71.47	25.1	.5005	.06765	531.11	.0081
13	290.69	230.73	114.48	70.17	17.7	.5005	.06765	475.08	.0081
13	289.95	230.63	114.08	70.16	17.6	.5005	.06765	473.65	.0081
13	289.33	230.84	113.93	70.15	17.3	.5005	.06765	471.44	.0081
19	249.88	176.80	110.43	73.11	25.1	.5005	.06765	524.47	.0081
19	248.95	176.72	110.61	73.11	24.9	.5005	.06765	521.76	.0081
19	251.16	176.89	110.72	73.12	25.5	.5005	.06765	527.30	.0081
20	249.66	178.00	91.42	73.04	24.6	.5005	.06765	524.34	.0081
20	250.78	177.82	92.22	73.06	25.0	.5005	.06765	526.25	.0081
20	249.80	177.57	88.44	73.06	24.8	.5005	.06765	524.73	.0081
22	249.75	197.80	118.12	71.80	17.2	.5005	.06765	458.47	.0081

22	250.11	196.41	117.89	71.89	17.8	.5005	.06765	463.05	.0081
22	249.58	198.16	118.18	71.78	17.0	.5005	.06765	458.61	.0081
25	249.95	218.28	116.95	70.55	10.1	.5005	.06765	385.94	.0081
25	249.49	218.18	117.12	70.55	10.0	.5005	.06765	386.07	.0081
25	249.58	217.58	117.27	70.59	10.2	.5005	.06765	387.99	.0081
28	209.49	146.72	125.98	74.80	24.7	.5005	.06765	462.08	.0081
28	210.18	146.27	126.16	74.84	25.1	.5005	.06765	464.81	.0081
28	209.68	145.46	125.83	74.89	25.3	.5005	.06765	463.45	.0081
29	210.75	146.42	91.48	74.83	25.2	.5005	.06765	492.07	.0081
29	210.13	146.27	91.53	74.84	25.1	.5005	.06765	490.15	.0081
29	210.37	146.72	91.36	74.81	25.0	.5005	.06765	490.81	.0081
31	209.35	163.43	112.41	73.68	17.4	.5005	.06765	425.82	.0081
31	209.59	163.59	111.42	73.67	17.4	.5005	.06765	424.46	.0081
32	210.50	163.75	91.26	73.67	17.6	.5005	.06765	431.98	.0081
32	210.09	164.96	90.51	73.59	17.0	.5005	.06765	428.32	.0081
32	210.65	163.27	91.07	73.70	17.9	.5005	.06765	433.20	.0081
33	210.42	164.56	74.42	73.62	17.3	.5005	.06765	433.04	.0081
33	210.29	164.32	74.46	73.63	17.4	.5005	.06765	429.18	.0081
33	210.02	164.16	74.43	73.64	17.3	.5005	.06765	432.59	.0081
34	210.64	182.74	116.55	72.44	10.1	.5005	.06765	360.96	.0081
34	210.98	182.04	116.91	72.49	10.5	.5005	.06765	363.73	.0081
34	211.17	183.00	116.71	72.43	10.2	.5005	.06765	363.59	.0081
39	291.66	210.25	97.88	71.39	24.8	.5005	.06765	553.09	.0081
39	291.34	209.68	97.93	71.42	25.0	.5005	.06765	553.07	.0081
39	291.48	209.48	98.29	71.43	25.0	.5005	.06765	554.97	.0081
41	289.49	230.94	90.65	70.14	17.3	.5005	.06765	481.15	.0081
41	291.19	230.94	90.92	70.16	17.8	.5005	.06765	486.28	.0081
41	289.27	231.46	90.34	70.11	17.1	.5005	.06765	477.99	.0081
42	291.74	254.19	84.26	68.79	10.7	.5005	.06765	416.62	.0081
42	290.42	256.30	81.79	68.66	9.7	.5005	.06765	409.98	.0081
42	291.20	254.97	83.89	68.74	10.3	.5005	.06765	410.05	.0081
43	289.10	229.70	92.51	70.21	17.6	.5005	.06765	488.10	.0081
43	288.98	229.50	92.49	70.22	17.7	.5005	.06765	488.43	.0081
43	289.36	229.19	92.65	70.24	17.9	.5005	.06765	491.51	.0081
44	289.43	208.23	97.01	71.49	24.9	.5005	.06765	553.81	.0081
44	289.19	208.04	97.02	71.50	24.9	.5005	.06765	554.03	.0081
44	289.44	207.95	97.12	71.51	25.0	.5005	.06765	555.11	.0081
45	289.58	253.52	110.28	68.81	10.3	.5005	.06765	407.81	.0081
45	290.24	254.19	110.31	68.78	10.3	.5005	.06765	407.24	.0081
45	290.00	253.41	110.28	68.82	10.5	.5005	.06765	408.80	.0081
46	247.96	195.50	85.51	71.93	17.5	.5005	.06765	461.97	.0081
46	249.09	195.50	84.95	71.94	17.8	.5005	.06765	465.57	.0081
46	248.38	195.32	85.48	71.94	17.7	.5005	.06765	464.87	.0081
47	249.58	217.39	76.64	70.60	10.3	.5005	.06765	394.81	.0081
47	249.11	217.29	76.67	70.60	10.2	.5005	.06765	392.43	.0081
47	250.03	218.87	76.57	70.51	9.9	.5005	.06765	390.12	.0081
48	209.48	146.50	82.05	74.82	24.8	.5005	.06765	490.20	.0081
48	209.77	146.57	81.92	74.82	24.8	.5005	.06765	490.76	.0081
48	210.18	146.50	81.75	74.82	25.0	.5005	.06765	491.85	.0081
49	210.18	146.94	106.99	74.79	24.8	.5005	.06765	484.72	.0081
49	209.77	146.87	106.97	74.80	24.7	.5005	.06765	484.49	.0081
49	210.13	146.79	106.86	74.80	24.9	.5005	.06765	484.65	.0081
50	211.06	146.79	120.43	74.81	25.2	.5005	.06765	475.16	.0081
50	211.00	147.16	120.92	74.78	25.0	.5005	.06765	473.90	.0081
50	211.06	147.09	120.84	74.79	25.0	.5005	.06765	473.46	.0081
10	291.75	210.35	90.39	71.38	24.8	.5000	.05267	357.56	.0084
10	291.43	208.52	91.19	71.49	25.4	.5000	.05267	362.07	.0084
10	291.53	208.81	91.09	71.47	25.3	.5000	.05267	362.88	.0084
11	290.49	207.66	112.88	71.53	25.4	.5000	.05267	359.29	.0084
11	290.89	209.19	112.58	71.45	25.0	.5000	.05267	357.19	.0084
11	291.05	208.23	112.88	71.50	25.4	.5000	.05267	359.80	.0084
12	292.66	209.19	74.96	71.46	25.5	.5000	.05267	362.41	.0084
12	290.05	208.81	76.05	71.46	24.9	.5000	.05267	357.97	.0084
12	291.42	208.62	75.69	71.48	25.3	.5000	.05267	362.41	.0084
13	290.28	230.11	122.44	70.20	17.8	.5000	.05267	317.56	.0084
13	289.84	230.63	121.91	70.16	17.5	.5000	.05267	315.63	.0084

13	290.47	231.66	122.05	70.11	17.4	.5000	.05267	314.14	.0084
15	290.27	232.08	70.99	70.08	17.2	.5000	.05267	317.99	.0084
15	290.69	232.18	71.49	70.08	17.3	.5000	.05267	317.77	.0084
15	291.12	231.56	72.00	70.12	17.6	.5000	.05267	318.58	.0084
16	290.84	254.63	116.69	68.76	10.3	.5000	.05267	279.28	.0084
16	290.87	255.19	116.84	68.73	10.2	.5000	.05267	280.43	.0084
18	290.08	256.19	64.99	68.66	9.7	.5000	.05267	285.42	.0084
18	290.75	255.86	64.99	68.69	9.9	.5000	.05267	285.62	.0084
18	289.56	255.30	65.57	68.71	9.8	.5000	.05267	288.41	.0084
19	248.44	176.80	118.39	73.10	24.7	.5000	.05267	332.70	.0084
19	248.62	177.31	118.33	73.07	24.5	.5000	.05267	331.79	.0084
19	249.57	176.97	118.54	73.10	25.0	.5000	.05267	333.93	.0084
20	249.52	177.74	91.59	73.05	24.6	.5000	.05267	335.66	.0084
20	251.03	177.14	92.47	73.10	25.4	.5000	.05267	339.78	.0084
20	250.15	177.48	91.24	73.07	24.9	.5000	.05267	338.15	.0084
21	249.61	176.04	68.19	73.16	25.4	.5000	.05267	340.39	.0084
21	249.67	175.87	68.51	73.17	25.4	.5000	.05267	341.61	.0084
21	250.15	176.80	68.89	73.12	25.2	.5000	.05267	341.48	.0084
22	251.01	197.61	118.10	71.82	17.6	.5000	.05267	299.42	.0084
22	250.02	197.52	118.11	71.82	17.4	.5000	.05267	298.25	.0084
22	250.63	197.89	118.75	71.80	17.4	.5000	.05267	297.56	.0084
23	249.73	197.43	91.35	71.82	17.3	.5000	.05267	301.56	.0084
23	249.82	197.80	91.31	71.80	17.2	.5000	.05267	299.64	.0084
28	210.57	147.83	121.71	74.74	24.5	.5000	.05267	309.66	.0084
28	210.83	147.16	123.28	74.78	24.9	.5000	.05267	310.84	.0084
28	211.12	147.01	123.43	74.79	25.1	.5000	.05267	311.88	.0084
29	210.67	147.16	92.28	74.78	24.9	.5000	.05267	312.34	.0084
29	210.64	146.79	91.91	74.81	25.0	.5000	.05267	313.86	.0084
29	210.38	146.50	91.43	74.82	25.1	.5000	.05267	313.68	.0084
30	210.07	147.09	61.35	74.78	24.7	.5000	.05267	315.01	.0084
30	210.06	146.94	61.27	74.79	24.8	.5000	.05267	315.10	.0084
30	210.23	146.72	61.57	74.81	24.9	.5000	.05267	316.01	.0084
31	209.95	164.32	115.28	73.63	17.2	.5000	.05267	275.66	.0084
31	210.32	163.92	115.10	73.66	17.5	.5000	.05267	277.32	.0084
31	209.93	163.59	114.93	73.68	17.5	.5000	.05267	277.51	.0084
32	210.24	163.35	92.15	73.69	17.7	.5000	.05267	280.50	.0084
32	209.63	164.16	91.47	73.64	17.2	.5000	.05267	277.74	.0084
32	210.24	164.00	91.78	73.65	17.5	.5000	.05267	278.28	.0084
33	210.04	164.16	56.78	73.64	17.3	.5000	.05267	281.25	.0084
33	209.93	164.00	56.97	73.65	17.4	.5000	.05267	283.01	.0084
33	210.02	163.92	56.91	73.66	17.4	.5000	.05267	281.20	.0084
34	210.44	182.91	113.38	72.43	10.0	.5000	.05267	242.44	.0084
34	210.20	182.91	113.07	72.42	9.9	.5000	.05267	242.87	.0084
34	210.06	182.39	113.25	72.46	10.1	.5000	.05267	243.14	.0084
37	251.04	198.07	65.82	71.80	17.5	.5000	.05267	303.35	.0084
37	249.25	197.61	65.30	71.81	17.1	.5000	.05267	300.18	.0084
37	252.53	197.80	65.38	71.82	18.0	.5000	.05267	309.34	.0084
38	249.59	217.49	116.60	70.59	10.3	.5000	.05267	265.79	.0084
38	248.31	217.39	117.65	70.59	9.9	.5000	.05267	257.46	.0084
38	249.74	217.49	117.06	70.60	10.3	.5000	.05267	263.88	.0084
10	290.27	207.66	90.79	71.53	25.4	.5010	.05325	373.08	.0138
10	290.41	207.66	91.79	71.53	25.4	.5010	.05325	373.28	.0138
10	290.07	207.85	91.82	71.52	25.2	.5010	.05325	371.16	.0138
11	290.17	209.00	119.15	71.45	24.9	.5010	.05325	367.47	.0138
11	290.13	208.71	118.64	71.47	25.0	.5010	.05325	367.26	.0138
11	290.03	208.52	118.33	71.48	25.0	.5010	.05325	367.55	.0138
12	289.66	209.10	77.46	71.44	24.7	.5010	.05325	367.74	.0138
12	289.65	208.23	78.00	71.49	25.0	.5010	.05325	368.84	.0138
12	289.68	207.95	78.14	71.51	25.1	.5010	.05325	369.91	.0138
14	291.23	230.94	91.89	70.16	17.8	.5010	.05325	331.13	.0138
14	290.85	231.56	91.65	70.12	17.5	.5010	.05325	323.26	.0138
14	291.07	231.15	91.72	70.14	17.7	.5010	.05325	329.70	.0138
15	290.69	230.01	73.96	70.21	18.0	.5010	.05325	331.76	.0138
15	290.44	230.53	73.79	70.18	17.7	.5010	.05325	330.26	.0138
15	290.96	231.25	73.78	70.14	17.6	.5010	.05325	330.26	.0138
17	291.77	255.86	90.61	68.70	10.2	.5010	.05325	289.00	.0138

17	291.34	256.19	90.62	68.67	10.0	.5010	.05325	290.78	.0138
17	291.55	256.53	91.51	68.65	10.0	.5010	.05325	292.61	.0138
18	290.85	256.53	64.47	68.65	9.8	.5010	.05325	297.59	.0138
18	292.30	256.19	64.44	68.68	10.3	.5010	.05325	295.55	.0138
18	291.30	256.08	65.13	68.68	10.0	.5010	.05325	294.27	.0138
19	252.37	178.76	114.28	73.01	25.1	.5010	.05325	348.54	.0138
19	251.52	178.00	115.19	73.05	25.2	.5010	.05325	348.74	.0138
19	251.58	178.00	114.77	73.05	25.2	.5010	.05325	348.98	.0138
20	250.94	177.23	91.87	73.09	25.3	.5010	.05325	350.03	.0138
20	250.20	177.23	91.85	73.09	25.1	.5010	.05325	349.34	.0138
20	250.65	177.48	91.68	73.08	25.1	.5010	.05325	349.69	.0138
21	249.42	177.31	68.81	73.08	24.8	.5010	.05325	350.57	.0138
21	249.62	177.57	68.59	73.06	24.8	.5010	.05325	350.25	.0138
21	250.42	177.65	68.75	73.06	25.0	.5010	.05325	351.38	.0138
22	249.85	196.14	114.27	71.90	17.8	.5010	.05325	310.27	.0138
22	249.42	196.41	114.93	71.88	17.6	.5010	.05325	308.12	.0138
22	249.69	196.69	114.83	71.87	17.6	.5010	.05325	308.53	.0138
23	249.55	196.60	92.02	71.87	17.6	.5010	.05325	310.00	.0138
23	251.43	196.87	91.14	71.87	18.0	.5010	.05325	312.66	.0138
23	250.03	196.41	91.42	71.89	17.8	.5010	.05325	309.98	.0138
24	251.80	198.35	64.58	71.78	17.6	.5010	.05325	315.57	.0138
24	251.42	197.98	64.98	71.80	17.6	.5010	.05325	309.47	.0138
24	250.00	197.52	65.64	71.82	17.4	.5010	.05325	315.79	.0138
28	209.45	146.57	117.08	74.81	24.7	.5010	.05325	320.50	.0138
28	209.49	146.94	117.02	74.79	24.6	.5010	.05325	319.95	.0138
28	209.93	146.05	117.00	74.85	25.1	.5010	.05325	322.75	.0138
29	209.20	146.27	91.23	74.83	24.8	.5010	.05325	323.44	.0138
29	209.48	145.46	91.44	74.89	25.2	.5010	.05325	324.93	.0138
29	209.64	145.76	91.68	74.87	25.1	.5010	.05325	324.88	.0138
30	210.52	146.50	62.38	74.83	25.1	.5010	.05325	328.46	.0138
30	209.45	145.76	62.30	74.87	25.1	.5010	.05325	327.71	.0138
30	209.52	146.20	62.14	74.84	24.9	.5010	.05325	326.80	.0138
31	209.70	163.27	115.86	73.70	17.6	.5010	.05325	285.94	.0138
31	210.28	163.59	116.77	73.68	17.6	.5010	.05325	287.35	.0138
31	209.70	164.08	116.20	73.64	17.2	.5010	.05325	284.10	.0138
32	209.88	163.75	91.15	73.67	17.4	.5010	.05325	287.89	.0138
32	210.12	163.92	90.83	73.66	17.5	.5010	.05325	288.99	.0138
32	210.36	163.59	91.29	73.68	17.7	.5010	.05325	288.31	.0138
33	209.92	164.16	59.27	73.64	17.3	.5010	.05325	290.71	.0138
33	210.07	164.32	59.85	73.63	17.3	.5010	.05325	292.82	.0138
33	209.63	164.32	59.60	73.63	17.1	.5010	.05325	288.82	.0138
34	210.42	183.87	116.62	72.36	9.6	.5010	.05325	247.65	.0138
34	210.66	182.39	116.87	72.46	10.3	.5010	.05325	253.55	.0138
34	209.62	182.39	115.80	72.45	9.9	.5010	.05325	248.36	.0138
35	209.34	180.66	91.96	72.56	10.5	.5010	.05325	256.94	.0138
35	210.32	182.30	92.12	72.46	10.2	.5010	.05325	256.53	.0138
35	209.28	182.39	91.05	72.45	9.8	.5010	.05325	257.64	.0138
36	210.24	182.47	55.87	72.45	10.1	.5010	.05325	252.68	.0138
36	210.14	183.08	55.73	72.41	9.8	.5010	.05325	236.73	.0138
36	210.28	183.17	55.89	72.41	9.8	.5010	.05325	257.77	.0138
37	290.33	229.80	92.25	70.22	17.9	.5010	.05325	333.65	.0138
37	290.41	231.46	92.08	70.12	17.4	.5010	.05325	321.91	.0138
37	291.25	231.56	91.46	70.12	17.6	.5010	.05325	327.21	.0138
39	250.88	196.60	65.69	71.88	18.0	.5010	.05325	319.56	.0138
39	249.56	196.78	66.03	71.86	17.5	.5010	.05325	313.79	.0138
39	250.09	196.87	65.89	71.86	17.6	.5010	.05325	317.80	.0138
10	289.75	208.62	90.67	71.47	24.9	.3750	.05217	363.10	.0091
10	289.71	208.43	90.66	71.48	24.9	.3750	.05217	364.46	.0091
10	290.89	207.47	91.28	71.55	25.6	.3750	.05217	366.45	.0091
11	292.26	207.95	118.01	71.53	25.8	.3750	.05217	362.53	.0091
11	290.19	208.04	118.07	71.51	25.2	.3750	.05217	359.61	.0091
11	290.41	208.52	118.23	71.48	25.1	.3750	.05217	360.94	.0091
12	292.59	207.09	78.79	71.59	26.2	.3750	.05217	370.38	.0091
12	289.55	207.37	77.83	71.54	25.3	.3750	.05217	364.82	.0091
12	290.33	208.52	77.44	71.48	25.1	.3750	.05217	364.21	.0091
13	291.00	230.32	119.55	70.19	18.0	.3750	.05217	324.19	.0091

13	290.16	231.77	118.80	70.10	17.3	.3750	.05217	321.49	.0091
13	290.92	231.66	118.14	70.11	17.5	.3750	.05217	321.22	.0091
15	289.99	231.87	72.75	70.09	17.2	.3750	.05217	325.85	.0091
15	290.92	231.56	72.85	70.12	17.5	.3750	.05217	328.16	.0091
15	290.86	230.94	73.17	70.15	17.7	.3750	.05217	329.09	.0091
19	250.97	177.91	120.12	73.05	25.0	.3750	.05217	340.34	.0091
19	249.97	178.08	119.73	73.03	24.7	.3750	.05217	338.10	.0091
19	250.59	176.80	119.79	73.12	25.4	.3750	.05217	340.89	.0091
20	249.96	176.72	91.91	73.12	25.2	.3750	.05217	342.68	.0091
20	248.97	177.23	91.65	73.08	24.7	.3750	.05217	341.71	.0091
20	250.51	177.23	90.87	73.09	25.1	.3750	.05217	342.73	.0091
21	250.44	176.72	70.14	73.12	25.3	.3750	.05217	346.70	.0091
21	249.73	176.97	70.06	73.10	25.0	.3750	.05217	345.06	.0091
21	249.83	176.97	70.06	73.10	25.0	.3750	.05217	344.84	.0091
22	251.35	197.52	119.49	71.83	17.8	.3750	.05217	309.58	.0091
22	250.41	197.80	119.09	71.81	17.4	.3750	.05217	307.28	.0091
22	251.41	197.80	119.60	71.82	17.7	.3750	.05217	309.23	.0091
23	250.62	195.96	91.19	71.92	18.1	.3750	.05217	313.26	.0091
23	249.95	198.07	90.78	71.79	17.1	.3750	.05217	311.74	.0091
23	249.43	197.43	91.03	71.82	17.2	.3750	.05217	310.10	.0091
24	249.43	197.33	65.72	71.83	17.3	.3750	.05217	311.51	.0091
24	249.78	195.86	66.50	71.92	17.9	.3750	.05217	314.78	.0091
24	249.12	196.14	66.24	71.90	17.6	.3750	.05217	313.41	.0091
27	251.05	220.57	63.53	70.42	9.7	.3750	.05217	285.56	.0091
27	250.91	219.97	63.55	70.45	9.8	.3750	.05217	287.19	.0091
27	249.74	219.37	63.52	70.48	9.7	.3750	.05217	287.99	.0091
28	209.90	146.94	116.88	74.79	24.7	.3750	.05217	313.70	.0091
28	210.52	146.72	118.21	74.81	25.0	.3750	.05217	315.33	.0091
28	210.19	146.50	117.23	74.82	25.0	.3750	.05217	316.14	.0091
29	210.91	146.05	91.30	74.86	25.5	.3750	.05217	321.62	.0091
29	209.97	146.50	90.80	74.82	24.9	.3750	.05217	319.73	.0091
30	209.86	145.76	61.81	74.87	25.2	.3750	.05217	323.41	.0091
30	209.95	145.76	61.81	74.87	25.3	.3750	.05217	324.09	.0091
30	209.68	146.13	61.87	74.85	25.0	.3750	.05217	323.36	.0091
31	210.77	164.64	119.20	73.61	17.4	.3750	.05217	285.07	.0091
31	209.44	163.84	115.40	73.66	17.3	.3750	.05217	285.90	.0091
31	209.85	163.67	115.57	73.67	17.5	.3750	.05217	285.92	.0091
32	210.26	164.32	90.39	73.63	17.3	.3750	.05217	290.35	.0091
32	210.64	164.00	90.89	73.66	17.6	.3750	.05217	291.85	.0091
32	210.46	163.75	90.87	73.67	17.6	.3750	.05217	293.06	.0091
33	210.02	162.87	57.32	73.72	17.9	.3750	.05217	297.52	.0091
33	209.36	162.87	57.35	73.72	17.6	.3750	.05217	296.64	.0091
33	210.80	163.43	57.81	73.69	17.9	.3750	.05217	296.33	.0091
34	210.28	181.95	119.46	72.49	10.3	.3750	.05217	265.26	.0091
34	210.42	182.04	119.86	72.48	10.3	.3750	.05217	264.51	.0091
34	210.23	182.21	119.58	72.47	10.2	.3750	.05217	265.46	.0091
36	209.19	182.39	53.18	72.45	9.8	.3750	.05217	278.18	.0091
36	209.01	181.95	53.15	72.48	9.9	.3750	.05217	278.24	.0091
36	210.02	181.87	53.11	72.49	10.3	.3750	.05217	280.12	.0091
10	289.28	208.52	88.79	71.47	24.8	.3775	.05257	370.34	.0148
10	289.22	208.23	88.05	71.49	24.9	.3775	.05257	370.83	.0148
10	291.33	210.16	88.45	71.39	24.8	.3775	.05257	370.80	.0148
11	291.31	210.64	118.88	71.36	24.6	.3775	.05257	367.74	.0148
11	292.19	210.25	118.09	71.39	25.0	.3775	.05257	371.55	.0148
11	293.36	209.39	118.15	71.45	25.6	.3775	.05257	373.88	.0148
13	290.30	231.04	119.45	70.14	17.5	.3775	.05257	331.43	.0148
13	290.97	231.25	119.40	70.14	17.6	.3775	.05257	330.16	.0148
13	290.56	230.42	119.46	70.18	17.8	.3775	.05257	331.37	.0148
14	290.55	230.53	89.64	70.18	17.8	.3775	.05257	334.13	.0148
14	290.72	231.66	90.79	70.11	17.4	.3775	.05257	332.97	.0148
14	290.27	231.35	90.66	70.12	17.4	.3775	.05257	332.82	.0148
15	292.33	232.50	73.95	70.08	17.6	.3775	.05257	336.20	.0148
15	292.47	231.25	74.81	70.15	18.0	.3775	.05257	339.03	.0148
15	291.37	231.46	74.99	70.13	17.7	.3775	.05257	335.37	.0148
18	292.46	255.97	66.31	68.70	10.4	.3775	.05257	302.98	.0148
18	291.95	256.19	66.39	68.68	10.2	.3775	.05257	298.93	.0148

18	290.80	256.19	68.05	68.67	9.9	.3775	.05257	301.91	.0148
19	251.39	178.34	123.17	73.03	25.0	.3775	.05257	350.11	.0148
19	251.16	178.42	123.25	73.02	24.9	.3775	.05257	348.94	.0148
19	251.19	178.42	123.27	73.02	24.9	.3775	.05257	348.70	.0148
20	249.74	177.48	91.25	73.07	24.8	.3775	.05257	349.88	.0148
20	249.76	177.23	90.92	73.09	24.9	.3775	.05257	350.64	.0148
20	248.85	176.72	91.58	73.11	24.9	.3775	.05257	349.20	.0148
21	250.95	177.65	69.62	73.07	25.1	.3775	.05257	354.03	.0148
21	250.24	177.23	70.19	73.09	25.1	.3775	.05257	353.37	.0148
21	250.56	176.89	70.48	73.11	25.3	.3775	.05257	353.78	.0148
22	249.34	196.32	117.69	71.89	17.6	.3775	.05257	314.38	.0148
22	249.50	196.69	117.58	71.87	17.5	.3775	.05257	313.88	.0148
22	249.98	197.24	117.70	71.84	17.5	.3775	.05257	314.47	.0148
23	249.35	197.15	91.43	71.84	17.3	.3775	.05257	315.27	.0148
23	250.53	196.97	91.42	71.86	17.7	.3775	.05257	313.63	.0148
23	249.20	196.87	91.19	71.85	17.4	.3775	.05257	315.65	.0148
24	249.29	196.32	66.31	71.89	17.6	.3775	.05257	317.34	.0148
24	248.99	196.51	65.99	71.88	17.4	.3775	.05257	317.24	.0148
24	248.91	196.69	66.46	71.86	17.3	.3775	.05257	316.56	.0148
28	210.79	147.31	112.99	74.77	24.9	.3775	.05257	323.29	.0148
28	210.27	146.27	112.35	74.84	25.1	.3775	.05257	323.95	.0148
28	211.02	147.38	112.06	74.77	24.9	.3775	.05257	323.05	.0148
29	209.64	146.72	91.27	74.80	24.7	.3775	.05257	324.26	.0148
29	210.18	146.50	91.51	74.82	25.0	.3775	.05257	325.53	.0148
29	210.03	146.35	91.74	74.83	25.0	.3775	.05257	325.19	.0148
30	210.47	146.72	63.27	74.81	25.0	.3775	.05257	328.94	.0148
30	210.03	146.72	63.39	74.81	24.9	.3775	.05257	328.54	.0148
30	210.08	146.35	64.06	74.83	25.0	.3775	.05257	328.79	.0148
31	210.84	164.64	115.78	73.61	17.4	.3775	.05257	291.61	.0148
31	210.14	164.32	114.23	73.63	17.3	.3775	.05257	291.54	.0148
31	210.65	164.32	115.10	73.63	17.5	.3775	.05257	291.85	.0148
32	210.30	163.19	91.35	73.71	17.8	.3775	.05257	298.15	.0148
32	210.37	163.51	91.36	73.68	17.7	.3775	.05257	297.89	.0148
32	210.15	163.67	91.03	73.67	17.6	.3775	.05257	297.07	.0148
33	209.37	163.84	61.73	73.66	17.2	.3775	.05257	297.54	.0148
33	209.73	163.51	61.61	73.68	17.5	.3775	.05257	298.72	.0148
33	209.28	163.35	61.88	73.69	17.4	.3775	.05257	297.16	.0148
34	210.86	182.04	117.11	72.49	10.5	.3775	.05257	268.34	.0148
34	210.18	182.47	116.78	72.45	10.1	.3775	.05257	269.42	.0148
34	210.55	182.74	117.15	72.44	10.1	.3775	.05257	265.83	.0148
38	290.43	208.52	75.25	71.48	25.1	.3775	.05257	375.07	.0148
38	291.00	209.29	77.00	71.44	25.0	.3775	.05257	374.43	.0148
38	291.68	209.68	76.71	71.42	25.0	.3775	.05257	374.15	.0148
11	290.99	208.04	112.05	71.52	25.4	.5000	.05290	381.24	.0197
11	290.23	208.62	111.38	71.47	25.0	.5000	.05290	378.39	.0197
11	290.12	208.81	110.73	71.46	24.9	.5000	.05290	378.04	.0197
12	291.66	209.96	77.55	71.41	24.9	.5000	.05290	383.93	.0197
12	291.37	209.68	77.60	71.42	25.0	.5000	.05290	384.28	.0197
12	291.80	209.48	77.69	71.44	25.1	.5000	.05290	386.81	.0197
21	251.25	177.48	70.62	73.08	25.3	.5000	.05290	361.64	.0197
21	251.01	177.06	71.07	73.11	25.4	.5000	.05290	363.50	.0197
21	250.88	177.48	71.16	73.08	25.2	.5000	.05290	364.25	.0197
28	211.00	146.05	103.55	74.86	25.5	.5000	.05290	335.64	.0197
28	210.40	146.50	102.13	74.82	25.1	.5000	.05290	332.48	.0197
28	210.73	146.94	103.91	74.80	25.0	.5000	.05290	332.34	.0197
30	210.44	146.13	63.14	74.85	25.3	.5000	.05290	340.32	.0197
30	210.58	146.42	63.03	74.83	25.2	.5000	.05290	339.59	.0197
30	210.88	146.72	63.39	74.81	25.1	.5000	.05290	340.33	.0197
37	250.88	177.14	106.73	73.10	25.3	.5000	.05290	356.52	.0197
37	250.81	176.38	107.20	73.15	25.6	.5000	.05290	357.90	.0197
37	249.81	176.80	106.86	73.11	25.1	.5000	.05290	355.77	.0197
38	249.41	176.72	135.44	73.12	25.0	.5000	.05290	348.10	.0197
38	249.76	176.55	135.63	73.13	25.2	.5000	.05290	349.39	.0197
38	249.55	176.89	136.03	73.11	25.0	.5000	.05290	348.34	.0197
39	251.04	177.06	171.85	73.11	25.4	.5000	.05290	337.93	.0197
39	251.75	176.97	171.95	73.12	25.6	.5000	.05290	339.22	.0197

39	250.73	177.31	171.66	73.09	25.2	.5000	.05290	337.66	.0197
40	251.43	178.08	177.88	73.04	25.1	.5000	.05290	332.30	.0197
40	250.53	177.57	177.11	73.07	25.0	.5000	.05290	325.66	.0197
40	250.72	177.31	177.28	73.09	25.2	.5000	.05290	328.96	.0197
41	249.11	177.14	187.59	73.09	24.8	.5000	.05290	315.90	.0197
41	249.24	176.46	187.06	73.13	25.1	.5000	.05290	311.49	.0197
41	249.03	176.38	186.72	73.13	25.0	.5000	.05290	310.65	.0197
42	249.97	176.29	194.93	73.15	25.4	.5000	.05290	297.97	.0197
42	249.84	176.55	194.90	73.13	25.2	.5000	.05290	296.38	.0197
42	249.63	177.06	194.61	73.10	25.0	.5000	.05290	298.77	.0197
43	210.58	145.91	130.42	74.87	25.4	.5000	.05290	327.95	.0197
43	210.70	147.24	130.44	74.78	24.9	.5000	.05290	325.65	.0197
43	210.89	147.38	130.06	74.77	24.9	.5000	.05290	325.49	.0197
44	209.62	146.50	152.11	74.82	24.8	.5000	.05290	306.14	.0197
44	209.33	146.64	152.17	74.81	24.6	.5000	.05290	306.08	.0197
44	210.81	146.27	152.29	74.84	25.3	.5000	.05290	302.91	.0197
45	209.38	146.50	163.65	74.82	24.7	.5000	.05290	277.68	.0197
45	209.48	146.05	163.82	74.85	25.0	.5000	.05290	278.37	.0197
45	209.51	147.01	163.47	74.78	24.5	.5000	.05290	277.98	.0197
46	209.43	145.17	147.42	74.91	25.4	.5000	.05290	310.10	.0197
46	209.94	145.83	147.41	74.87	25.2	.5000	.05290	310.34	.0197
46	209.86	145.91	147.28	74.86	25.2	.5000	.05290	310.00	.0197
47	291.06	209.77	154.24	71.41	24.8	.5000	.05290	369.78	.0197
47	290.42	207.95	153.51	71.52	25.3	.5000	.05290	372.66	.0197
48	209.75	182.74	76.29	72.43	9.8	.5000	.05290	265.17	.0197
48	209.52	181.95	76.64	72.48	10.1	.5000	.05290	264.24	.0197
48	209.98	182.21	76.72	72.47	10.1	.5000	.05290	260.41	.0197
51	209.46	181.69	173.14	72.50	10.1	.5000	.05290	219.65	.0197
51	209.66	182.21	173.21	72.47	10.0	.5000	.05290	220.49	.0197
51	209.64	182.39	173.15	72.45	9.9	.5000	.05290	219.63	.0197
52	210.92	183.00	183.56	72.42	10.1	.5000	.05290	208.03	.0197
52	211.08	183.26	183.78	72.41	10.1	.5000	.05290	207.36	.0197
52	211.29	183.26	183.46	72.41	10.2	.5000	.05290	207.04	.0197
53	210.50	183.26	187.24	72.40	9.9	.5000	.05290	189.60	.0197
53	209.65	182.74	186.42	72.43	9.8	.5000	.05290	190.56	.0197
53	210.26	182.74	187.06	72.44	10.0	.5000	.05290	195.38	.0197
20	250.28	177.31	91.75	73.08	25.0	1.0000	.05330	345.36	.0110
20	249.43	177.31	91.81	73.08	24.8	1.0000	.05330	343.65	.0110
20	249.97	177.74	91.55	73.06	24.8	1.0000	.05330	348.73	.0110
21	249.62	176.72	92.21	73.12	25.1	1.0000	.05330	343.32	.0110
21	249.98	176.97	92.06	73.10	25.1	1.0000	.05330	347.95	.0110
21	250.75	177.74	92.50	73.06	25.0	1.0000	.05330	342.28	.0110
20	251.00	177.65	91.30	73.07	25.1	1.0000	.05338	340.55	.0182
20	250.61	178.00	91.30	73.04	24.9	1.0000	.05338	337.16	.0182
20	251.04	178.68	91.47	73.00	24.8	1.0000	.05338	338.68	.0182
38	249.97	177.91	91.09	73.04	24.7	1.0000	.05338	335.85	.0182
38	250.42	178.00	91.33	73.04	24.8	1.0000	.05338	340.35	.0182
38	250.87	177.23	90.99	73.09	25.3	1.0000	.05338	343.97	.0182
20	250.63	177.65	91.01	73.07	25.0	1.0000	.05338	330.57	.0070
20	251.19	177.74	90.68	73.06	25.2	1.0000	.05338	330.88	.0070
20	251.07	177.82	90.82	73.06	25.1	1.0000	.05338	331.63	.0070
21	251.46	178.34	90.54	73.03	25.0	1.0000	.05338	329.61	.0070
21	250.88	178.42	90.82	73.02	24.8	1.0000	.05338	331.59	.0070
21	251.08	178.25	90.55	73.03	24.9	1.0000	.05338	330.75	.0070
20	250.91	178.59	90.74	73.01	24.7	1.0000	.05313	337.98	.0039
20	250.90	178.25	90.91	73.03	24.9	1.0000	.05313	337.61	.0039
20	250.70	177.74	91.31	73.06	25.0	1.0000	.05313	341.47	.0039
21	250.10	177.74	91.15	73.06	24.8	1.0000	.05313	335.50	.0039
21	251.76	178.25	91.28	73.04	25.1	1.0000	.05313	341.91	.0039
21	251.39	177.40	91.59	73.09	25.4	1.0000	.05313	339.65	.0039
10	290.69	208.52	91.48	71.48	25.2	.5000	.04378	242.29	.0103
10	290.49	208.52	92.08	71.48	25.1	.5000	.04378	242.45	.0103
10	291.21	208.81	91.81	71.47	25.2	.5000	.04378	243.20	.0103
11	290.73	209.10	122.75	71.45	25.0	.5000	.04378	240.26	.0103
11	291.38	209.68	122.97	71.42	25.0	.5000	.04378	240.41	.0103
11	291.21	209.77	122.75	71.41	24.9	.5000	.04378	239.87	.0103

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☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)*

Refrigerant flow through the short tube exapansion device was theoretically and experimentally investigated. The analysis was limited to initially subcooled R22 flowing through short tubes with 5 L/D 20. Flow dependency upon upstream subcooling, upstream pressure, downstream pressure, length, diameter, entrance chamfering and exit chamfering was determined. A flow model and flow charts were developed. Ninety-five percent of the data agrees with the prediction of the model within $\pm 5\%$.

A choking phenomena was observed when the downstream pressure was reduced below the liquid saturation pressure. Choking was not ideal because the flow rate gradually increased with further reduction in downstream pressure.

The pressure profile along the short tube was measured. Results showed that the downstream pressure waves were able to propagate upstream and that a large discontinuity in pressure existed at the tube inlet and outlet.

The flow was directly proportional and approximately linear to both upstream subcooling and upstream pressure. The flow displayed a nonlinear relationship to both tube length and diameter. The flow was directly proportional to tube diameter and indirectly proportional to tube length. Inlet chamfering caused up to a 25% increase in mass flow rate while the flow was unaffected by exit chamfering.

12. KEY WORDS *(Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)*

air conditioner; choked flow; expansion device; heat pump; restrictor; short tube restrictor

13. AVAILABILITY

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